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Drone Technology: A New Revolution in Precision Agriculture

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Agriculture is undergoing a major technological transformation as farmers face increasing pressure to produce more food with limited land, water, labour and other resources. Drone technology, also known as Unmanned Aerial Vehicle (UAV) technology, has emerged as an important component of modern precision agriculture. Agricultural drones can collect high-resolution images and other field information using RGB, multispectral, hyperspectral and thermal sensors. These observations enable farmers and agricultural professionals to monitor crop growth, identify water stress, detect nutrient deficiencies, locate weeds, recognize diseases and pests, estimate crop yield and assess field variability. Drones can also be used for targeted spraying and other precision operations. When drone observations are combined with Geographic Information Systems (GIS), remote sensing, Internet of Things (IoT), machine learning and artificial intelligence, field-level information can be converted into timely management decisions. Recent developments indicate that UAV-based systems are moving from simple aerial imaging toward intelligent and semi-autonomous agricultural operations. However, high initial investment, battery limitations, weather sensitivity, technical expertise, data processing requirements and regulatory considerations remain important challenges. The future of agricultural drones will depend on affordable equipment, improved sensors, longer flight duration, automated data interpretation and farmer-oriented services. Properly integrated into farm management, drone technology can improve input-use efficiency, reduce unnecessary field operations and contribute to productive, sustainable and climate-resilient agriculture.

1. Introduction

Agriculture has traditionally depended on field observation and experience for making decisions about crop production. Although farmers possess valuable practical knowledge, large and diversified farms are becoming increasingly difficult to monitor manually. Changes in climate, increasing production costs, shortage of agricultural labour and the need for efficient use of water and agrochemicals have increased the importance of precision agriculture.

Precision agriculture aims to manage crop production according to the actual conditions of different locations within a field. Instead of treating the entire field uniformly, farmers can identify areas that require more or less water, fertilizer or crop protection. Drone technology has become an important tool for obtaining this location-specific information.

An agricultural drone is a remotely operated or autonomous aerial platform equipped with cameras and sensors. It can fly over agricultural fields at relatively low altitude and collect detailed information within a short period. Research published in recent years has identified UAVs as an important technology for remote sensing, crop monitoring and precision farm management.

The major advantage of drones is their ability to provide **high-resolution, timely and flexible observations**. Satellite images are valuable for monitoring large areas, but clouds, revisit intervals and spatial resolution can sometimes limit their usefulness. Drones can be deployed when required and can focus on a particular field or crop.

Consequently, drone technology is transforming agriculture from conventional field inspection toward

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data-based and location-specific crop management.

2. How Agricultural Drones Work

A typical agricultural drone consists of several integrated components:

- Airframe and propulsion system
- Battery and power-management system
- Flight controller
- Navigation system
- Global Navigation Satellite System (GNSS)
- Camera or other sensors
- Communication system
- Data-storage system
- Image-processing and analysis software

The drone follows a predefined flight path over the field. During the flight, its sensors capture images or measurements at regular intervals. These data are subsequently processed to generate maps or other information useful for farm management.

The basic process can be represented as:

Drone Flight → Data Collection → Image Processing → Field Mapping → Analysis → Management Decision

Modern systems can add AI and machine-learning algorithms to automatically identify crop conditions and abnormalities. Recent research specifically highlights the growing integration of UAVs with deep learning for precision agriculture.

3. Sensors Used in Agricultural Drones

The usefulness of an agricultural drone depends greatly on its sensor.

3.1 RGB Cameras

RGB cameras record images in the visible red, green and blue portions of the spectrum. They are relatively inexpensive and can provide detailed visual information about:

- plant population;
- canopy development;
- visible disease symptoms;
- weed distribution;
- damaged plants; and
- field boundaries.

3.2 Multispectral Sensors

Multispectral cameras capture information from selected spectral bands, including wavelengths beyond the visible range. They can help identify differences in vegetation condition that may not be obvious to the human eye.

Vegetation indices such as the Normalized Difference Vegetation Index (NDVI) can be generated from suitable imagery and used for crop-health assessment.

3.3 Thermal Sensors

Thermal cameras measure emitted infrared radiation and provide information related to surface temperature. Crop canopy temperature can be useful for identifying areas experiencing water stress.

3.4 Hyperspectral Sensors

Hyperspectral sensors collect information across many narrow spectral bands. They provide detailed spectral signatures that can potentially assist in detecting subtle changes in crop health, nutrient status and disease.

However, hyperspectral systems generally require greater data-processing capacity and can be more expensive than conventional RGB or multispectral systems.

4. Major Applications of Drone Technology in Agriculture

4.1 Crop Health Monitoring

One of the most important uses of drones is rapid monitoring of crop health. A single flight can provide

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detailed information about crop variability across a field.

Drone imagery can help identify:

- weak crop areas;
- uneven plant growth;
- damaged sections;
- poor emergence;
- water-stressed zones; and
- areas requiring detailed ground inspection.

This enables farmers to focus their attention on specific locations instead of manually examining the entire field.

4.2 Detection of Water Stress

Water is one of the most important agricultural resources. Over-irrigation wastes water and energy, whereas inadequate irrigation can reduce crop productivity.

Thermal and multispectral drone imagery can help identify spatial variations in crop condition. Such information can be combined with soil moisture and weather observations to support more efficient irrigation decisions.

In this way, drones can contribute to **site-specific water management**.

4.3 Disease Detection

Plant diseases can spread rapidly when environmental conditions are favourable. Early identification is therefore extremely important.

Drone images can identify unusual colour, texture and canopy patterns associated with crop diseases. When these images are analysed using machine-learning or deep-learning models, automated disease identification becomes possible.

A 2023 review in *Precision Agriculture* reported the increasing use of drones for automated plant-disease detection and emphasized their potential to overcome the limitations of manual inspection over large areas. The objective is not simply to identify disease but to locate **where intervention is needed**.

4.4 Weed Detection and Management

Weeds compete with crops for water, nutrients, light and space. Conventional blanket herbicide application can increase chemical use and environmental risks.

Drone imagery can identify variations in plant appearance and help distinguish crops from weeds. When combined with AI, the resulting maps can support targeted weed-management operations.

Recent research has particularly examined UAV and AI integration for weed management, disease detection and pest control.

4.5 Precision Spraying

Agricultural drones are increasingly being developed for spraying applications. Instead of applying crop-protection products uniformly, drone-based systems can potentially target specific areas.

Advantages may include:

- rapid field coverage;
- reduced operator exposure;
- access to wet or difficult terrain;
- reduced crop damage from ground machinery;
- targeted application; and
- reduced unnecessary field movement.

However, spraying must always follow applicable agricultural and aviation regulations, label requirements and safe operating procedures.

Research reviews have identified crop monitoring and pesticide spraying as major application areas for agricultural drone technology.

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5. Drone Technology in Horticulture

Drones have particular value in horticultural crops because individual plants or trees can be monitored at high spatial resolution.

In orchards, drone imagery can assist with:

- tree counting;
- canopy mapping;
- assessment of tree vigour;
- identification of gaps;
- irrigation monitoring;
- disease surveillance;
- flowering assessment;
- fruit-load estimation; and
- yield prediction.

For crops such as mango, citrus, pomegranate, grapes and other perennial horticultural crops, repeated drone observations can create a digital record of crop development.

This can help agricultural experts move from occasional field inspection toward **continuous crop observation**.

6. Drone-Based Yield Estimation

Yield estimation before harvest is important for farmers, traders, food-processing industries and policymakers.

Drone images can provide information about:

- canopy area;
- plant density;
- biomass;
- flowering;
- fruit number;
- fruit size; and
- crop development.

Machine-learning algorithms can combine these characteristics with historical field information to develop yield-prediction models.

The accuracy of such models depends on crop type, sensor characteristics, image quality, growth stage, environmental conditions and the quality of field observations used for model development.

Therefore, drone-based yield estimation should be locally calibrated rather than assuming that one model will work equally well for every crop and region.

7. Integration of Drones with Artificial Intelligence

The real revolution in agricultural drone technology is occurring through the integration of UAVs with artificial intelligence.

A drone can collect thousands of images, but manually analysing every image would be time-consuming. AI can automatically process large datasets and identify patterns.

For example:

Drone Image → AI Model → Crop/Weed/Disease Classification → Location Map → Management Recommendation

Deep-learning methods have increasingly been applied to UAV imagery for crop monitoring and agricultural decision-making. Recent research describes the combination of UAVs and deep learning as an important direction for precision agriculture.

AI-enabled drones may eventually be capable of:

- identifying diseased plants automatically;
- detecting weeds;
- estimating crop biomass;
- identifying water-stressed areas;
- predicting yield;
- generating treatment maps; and

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- supporting autonomous agricultural operations.

This changes the role of the drone from merely an **imaging platform** to an **intelligent agricultural information system**.

8. Integration with Weather and Soil Information

Drone observations become more valuable when combined with other agricultural datasets.

For example:

Weather Forecast + Soil Moisture + Drone Imagery + Crop Stage + Historical Data = Better Farm Decision

Weather information can explain why crop stress is developing, while drone imagery can show exactly where the stress is occurring. Soil sensors can provide information about moisture conditions, and AI can combine all these datasets.

This integrated approach can support:

- irrigation scheduling;
- disease-risk forecasting;
- fertilizer management;
- pest management;
- heat-stress assessment; and
- harvest planning.

The combination of UAVs, IoT and other digital technologies is increasingly recognized as an important direction for smart farming.

9. Advantages of Agricultural Drones

The major advantages of drone technology include:

1. **High spatial resolution** – detailed information can be obtained at individual plant or field-section level.
2. **Rapid data collection** – large areas can be surveyed in a relatively short time.
3. **Flexible operation** – drones can be deployed when specific information is required.
4. **Early problem detection** – crop stress may be identified before severe visible damage occurs.
5. **Reduced field inspection time** – farmers can focus ground observations on problem areas.
6. **Better input management** – water, fertilizer and crop-protection products can potentially be applied more precisely.
7. **Improved documentation** – repeated flights create a time series of crop development.
8. **Support for AI-based agriculture** – drone imagery provides valuable data for machine-learning models.

Research reviews have associated agricultural drones with improved monitoring, operational efficiency and more data-driven management.

10. Limitations and Challenges

Despite their advantages, agricultural drones also have limitations.

Cost

High-quality drones, sensors, software and maintenance can require significant investment.

Battery limitations

Flight duration is restricted by battery capacity. Recent studies identify limited UAV battery life as an important practical challenge.

Weather conditions

Strong winds, rainfall and poor visibility can affect flight safety and image quality.

Data management

High-resolution drone flights can generate large quantities of data that require storage, processing and interpretation.

Skilled personnel

Operating drones, planning missions and interpreting imagery require appropriate technical knowledge.

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Regulatory requirements

Drone operations must comply with applicable aviation and agricultural regulations.

AI model limitations

AI models may perform poorly when applied to crops, locations or environmental conditions different from those represented in their training data.

Small-farmer accessibility

The benefits of drone technology should not be limited to large commercial farms. Custom-hiring services, agricultural cooperatives and service providers may help smaller farmers access drone-based services without purchasing complete systems.

11. Future Scope

The future of agricultural drones is moving toward greater automation and intelligence.

Several developments are likely to shape the next generation of agricultural UAVs:

Autonomous flight

Drones will increasingly be capable of automatic route planning and obstacle avoidance.

Improved sensors

Smaller and more affordable multispectral, thermal and hyperspectral sensors will increase agricultural applications.

AI-based interpretation

Automated image analysis will reduce the need for manual interpretation.

Drone–satellite integration

Combining high-resolution drone observations with large-area satellite monitoring can provide information at multiple spatial scales.

Swarm technology

Multiple drones may eventually cooperate to monitor large agricultural areas efficiently.

Edge computing

Data may increasingly be processed directly on the drone or nearby field equipment, reducing dependence on continuous internet connectivity.

Digital agriculture platforms

Drone observations may become part of integrated platforms combining weather, soil, satellite, crop and market information.

Recent research points toward multi-source data fusion, improved UAV equipment, AI-based analysis and broader agricultural monitoring as important future directions.

12. Conclusion

Drone technology has emerged as one of the most promising innovations in precision agriculture. By providing high-resolution aerial information, agricultural drones allow farmers and agricultural professionals to observe crop conditions more quickly and accurately than conventional field inspection alone.

Their applications now extend from crop monitoring and disease detection to weed identification, water-stress assessment, yield estimation and precision spraying. The integration of drones with multispectral and thermal sensors, artificial intelligence, machine learning, IoT and weather information is further increasing their potential.

However, drones should not be viewed simply as flying cameras. Their greatest value comes from the complete chain of **data collection, analysis and agricultural decision-making**. The future of drone-based agriculture will depend on affordable technology, reliable sensors, intelligent software, trained operators and farmer-oriented service models.

For countries such as India, where farms range from very small holdings to large commercial operations, service-based drone models and agricultural cooperatives could make this technology more

accessible. With appropriate regulation, training and local validation, drones can contribute significantly to efficient input use, improved crop management and sustainable agricultural production.

Drone technology is therefore not merely a new tool for observing farms—it is becoming an important component of the transition from conventional agriculture to data-driven precision agriculture.

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Smart Farming for a Changing Climate: The Role of Forecasting, Drones and AI

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Climate change is creating new uncertainties for agricultural production through irregular rainfall, rising temperature, droughts, heat waves, floods, pest outbreaks and other extreme weather events. Traditional farming practices alone are increasingly insufficient for managing these rapidly changing conditions. Smart farming offers a technology-driven approach in which weather forecasting, unmanned aerial vehicles (UAVs or drones), artificial intelligence (AI), remote sensing, sensors and digital decision-support systems are integrated to improve farm management. Weather and climate forecasting can help farmers select suitable crops, adjust sowing dates, schedule irrigation and prepare for extreme events. Drones equipped with RGB, multispectral, thermal or hyperspectral sensors can provide high-resolution information about crop health, water stress, nutrient deficiency and pest or disease occurrence. AI and machine-learning algorithms can transform these large datasets into useful predictions and management recommendations. Recent research shows increasing integration of AI, UAVs, IoT and remote sensing for precision and climate-smart agriculture. However, challenges such as high initial investment, limited technical skills, connectivity, data quality, battery limitations, regulatory requirements and unequal access remain important barriers. The future of smart farming therefore depends not only on advanced technology but also on affordable solutions, farmer training, local-language advisories and reliable agricultural extension services. Properly integrated, forecasting, drones and AI can strengthen agricultural resilience while improving productivity, resource-use efficiency and environmental sustainability.

1. Introduction

Agriculture is highly dependent on weather and climate. Temperature, rainfall, humidity, solar radiation, wind and soil moisture influence almost every stage of crop production. Climate change is making these factors more uncertain by altering rainfall distribution, increasing temperature extremes and contributing to more frequent droughts, floods and heat stress. Such changes create difficulties in deciding when to sow, how much water to apply, when to spray pesticides and which crop or variety is most suitable.

Climate-smart agriculture aims to improve agricultural productivity and resilience while reducing environmental impacts. Recent reviews describe climate-smart agriculture through three closely connected objectives: improving productivity, strengthening adaptation and reducing the environmental footprint of agricultural production.

Digital technologies are becoming important tools for achieving these objectives. Smart farming combines field sensors, satellite imagery, mobile applications, Internet of Things (IoT) devices, automated machinery, drones, artificial intelligence and weather information. Digital agriculture can support better management of water, fertilizer, pesticides, energy and labour while improving the quality and timeliness of farm decisions.

Among these technologies, **forecasting, drones and AI** have particular importance. Forecasting provides information about what is likely to happen; drones provide detailed information about what is happening in the field; and AI helps interpret the information

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and predict what may happen next. Their integration can therefore create a continuous cycle of **forecast–observe–analyse–decide–act**.

2. Weather and Climate Forecasting for Smart Farming

Weather forecasting is one of the most useful tools for climate-resilient agriculture. Farmers make numerous decisions according to expected weather conditions. Short-range forecasts can provide information about rainfall, temperature, wind and humidity, while medium- and long-range forecasts can assist in crop planning and seasonal management.

Forecasting can support:

- selection of suitable crops and varieties;
- determination of optimum sowing dates;
- irrigation scheduling;
- fertilizer application;
- pesticide and fungicide spraying;
- harvesting decisions;
- preparation for droughts, floods and heat waves;
- management of livestock during extreme weather;
- crop contingency planning.

The importance of forecasting for Indian agriculture has also been recognized through initiatives focusing on forecasting and decision-support systems for climate-resilient agriculture, particularly in rainfed regions.

The next generation of agricultural forecasting is moving beyond a simple weather bulletin. Forecast information can be combined with crop models, soil data, satellite observations and farm-level sensor data to generate **location-specific agricultural advisories**.

For example, a rainfall forecast alone may tell a farmer that substantial rainfall is expected. A smart decision-support system could additionally determine whether irrigation should be postponed, whether fertilizer application should be avoided, and whether the crop is at a growth stage particularly vulnerable to waterlogging.

Thus, the objective is not merely to forecast weather but to translate weather information into an **agricultural decision**.

3. Drones as the Eyes of Smart Farms

Unmanned aerial vehicles, commonly called drones, have emerged as important tools for precision agriculture. Unlike conventional field inspection, drones can survey large areas rapidly and provide detailed spatial information.

Agricultural drones may carry:

- RGB cameras;
- multispectral sensors;
- hyperspectral sensors;
- thermal cameras;
- LiDAR systems;
- specialized environmental sensors.

The resulting images can reveal differences within a field that may not be visible from the ground. UAV-based remote sensing is increasingly being combined with AI to identify crop stress, monitor crop growth, detect diseases and support precision management.

Major agricultural applications of drones

Crop health monitoring:

Changes in vegetation indices and spectral characteristics can indicate crop stress before symptoms become clearly visible to farmers.

Water-stress detection:

Thermal imagery can identify differences in canopy temperature and help locate areas requiring irrigation.

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Disease and pest detection:

High-resolution images can help identify abnormal plant patterns associated with diseases or pest attacks.

Nutrient management:

Spectral information can help identify spatial differences associated with nutrient deficiencies and guide variable-rate application.

Crop growth assessment:

Repeated drone flights can measure plant development, canopy cover and other indicators of crop growth.

Yield estimation:

Combining drone imagery with machine-learning algorithms can assist in estimating yield before harvest.

Spraying applications:

Agricultural drones can also be used for targeted application of crop-protection products where permitted and appropriately regulated.

Recent literature emphasizes that UAVs are particularly valuable because they provide high-resolution observations that can complement satellite and ground-based information.

4. Artificial Intelligence: Converting Data into Decisions

The rapid expansion of smart farming is producing enormous quantities of agricultural data. A single farm may generate information from weather stations, soil sensors, drones, satellites, machinery, mobile applications and historical production records.

Artificial intelligence provides methods for processing these complex datasets.

Machine learning can identify relationships between environmental conditions and crop responses. Deep-learning models can analyse images for disease detection, crop classification and stress identification. AI-based systems can also assist with yield prediction, irrigation recommendations, pest forecasting and resource allocation. Reviews published in recent years have documented the growing role of machine learning and AI across pre-harvest, harvest and post-harvest agricultural operations.

For example, an AI system could combine:

Weather forecast + soil moisture + crop stage + drone image + historical yield data

to estimate the probability of crop water stress. Instead of simply informing the farmer that the soil is becoming dry, the system could recommend an appropriate irrigation action.

This represents an important change from **data collection to intelligent decision support**.

5. Integration of Forecasting, Drones and AI

The greatest potential does not lie in using forecasting, drones or AI independently. Their integration can create a more powerful smart-farming system.

A possible integrated system

Step 1 – Forecasting:

Weather and seasonal climate information provides an estimate of upcoming environmental conditions.

Step 2 – Field observation:

Drones, satellites and IoT sensors continuously monitor crop and soil conditions.

Step 3 – Data integration:

Weather, soil, crop and remote-sensing datasets are combined.

Step 4 – AI analysis:

Machine-learning or deep-learning models identify patterns and predict crop responses.

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Step 5 – Decision support:

The system generates recommendations concerning irrigation, fertilizer, disease management, crop protection or harvesting.

Step 6 – Farm action:

Farmers or automated equipment implement the recommended intervention.

Step 7 – Feedback:

New observations are returned to the system, allowing the model to improve future recommendations.

This creates a dynamic **digital agricultural feedback loop** rather than a one-time advisory.

6. Contribution to Climate-Smart Agriculture

Smart farming technologies can contribute to all three major dimensions of climate-smart agriculture.

6.1 Improving productivity

Better information can help farmers apply inputs at the appropriate time and location. Early identification of crop stress can reduce yield losses, while forecasting can improve crop planning.

6.2 Improving climate resilience

Forecasting and early-warning systems can help farmers prepare for drought, excessive rainfall, heat waves and other extreme conditions. Digital technologies can also support contingency planning and adaptive farm management.

6.3 Reducing environmental impacts

Precision application of water, fertilizer and crop-protection products can reduce unnecessary input use. Digital agriculture is therefore increasingly considered a component of sustainable and climate-smart agricultural systems.

7. Role in Horticulture

The combination of drones, AI and forecasting has particular potential in horticultural crops because fruit and vegetable production requires close monitoring.

In orchards, drones can identify differences in tree vigour, canopy density and water stress. Thermal imagery can help locate water-stressed plants, while multispectral imagery can assist in monitoring vegetation condition.

AI can further analyse these observations to identify patterns associated with disease, nutrient deficiency or yield variation.

For horticultural crops such as mango, citrus, grapes, pomegranate, banana and vegetables, an integrated system could provide:

- disease-risk warnings;
- irrigation recommendations;
- flowering and fruit-development monitoring;
- canopy assessment;
- yield estimation;
- heat-stress alerts;
- harvest planning.

Such approaches can reduce the dependence on uniform management across an entire field or orchard.

8. Challenges and Limitations

Despite the promising potential, smart farming cannot be considered a universal solution without addressing practical limitations.

High initial cost

Drones, sensors, weather stations, software and computing infrastructure can be expensive for individual small and marginal farmers.

Technical expertise

Farmers and field-level agricultural personnel require training to interpret digital information and convert it into practical decisions.

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Data quality

AI models are only as reliable as the data used to train and operate them. Poor-quality weather, imagery or field observations can result in inaccurate recommendations.

Connectivity

Rural areas may have limited internet connectivity and inconsistent access to digital infrastructure.

Battery and operational limitations

Drones have limited flight duration and are affected by wind, rain and other environmental conditions. Recent UAV reviews identify battery life, operational cost and operator expertise among important adoption constraints.

Data ownership and privacy

Agricultural data can contain commercially important information. Clear policies are required concerning ownership, sharing, privacy and responsible AI.

Model reliability

An AI model trained under one climatic or agricultural condition may not perform equally well under another. Therefore, local validation is essential.

FAO has also emphasized the importance of responsible digital agriculture, including capacity development, data governance, ethical AI and inclusive access to digital innovation.

9. Future Prospects

The future of smart farming is likely to involve the integration of several technologies rather than dependence on one technology.

Important future directions include:

1. **AI-based hyperlocal weather forecasting** for individual farms and villages.
2. **Autonomous agricultural drones** for monitoring and precision operations.
3. **Multispectral and thermal imaging** for early crop-stress identification.
4. **Digital twins of farms** for simulation and decision support.
5. **Edge AI** for rapid analysis of field data without continuous cloud connectivity.
6. **Integration of satellite, drone and ground observations**.
7. **Farmer-friendly mobile advisories** in regional languages.
8. **Low-cost sensors and community-based weather stations**.
9. **Explainable AI** so that farmers understand why a recommendation is generated.
10. **AI-enabled climate-risk management** for drought, flood and heat-wave preparedness.

International work on digital agriculture increasingly emphasizes interoperability, responsible AI, data governance and accessibility so that technological benefits are not limited to large commercial farms.

10. Conclusion

Climate change requires agriculture to become more anticipatory, precise and adaptive. Smart farming provides an important pathway toward this transformation. Weather and climate forecasting can help farmers anticipate future risks; drones can provide detailed information about current field conditions; and artificial intelligence can transform complex agricultural data into useful predictions and recommendations.

The real strength of these technologies emerges when they are integrated into a single decision-support framework. Such integration can improve crop monitoring, irrigation management, pest and disease surveillance, input-use efficiency, yield forecasting and climate-risk management. Recent research confirms the increasing convergence of UAVs, AI, IoT, remote sensing and precision agriculture.

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However, technology alone will not make agriculture climate resilient. Affordable equipment, reliable connectivity, farmer training, local validation, transparent data governance and strong agricultural extension services are equally important. The future objective should therefore be "smart technology for every farmer" rather than technology only for large farms.

A well-designed combination of forecasting, drones and AI can help agriculture move from reactive farming to predictive and preventive farming, making food production more resilient, efficient and sustainable under a changing climate.

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Millets: The Future of Climate-Resilient and Nutritious Agriculture

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Climate change, declining natural resources, and increasing nutritional needs have created an urgent need for sustainable and resilient agricultural practices. Millets, often regarded as traditional and underutilized cereals, have gained renewed importance because of their ability to withstand drought, high temperatures, and low soil fertility while requiring relatively less water and external inputs. This article discusses the potential of millets as a future crop for achieving both environmental sustainability and nutritional security. Millets provide important nutrients such as protein, dietary fibre, minerals, vitamins, and antioxidants, making them an important part of a healthy and balanced diet. Their cultivation can also support resource conservation, strengthen the livelihoods of small-scale farmers, and improve agricultural resilience in climate-vulnerable regions. Despite these advantages, challenges related to production, processing, storage, marketing, consumer awareness, and value addition continue to limit their wider adoption. Addressing these constraints through technological innovation, policy support, improved market opportunities, and greater public awareness can promote the cultivation and consumption of millets. Thus, integrating millets into modern food and farming systems can contribute significantly to climate-resilient agriculture, sustainable livelihoods, and improved food and nutritional security.

Introduction

Agriculture is facing a new set of challenges in the form of rising temperatures, irregular rainfall, prolonged droughts, declining soil health and increasing pressure on natural resources. At the same time, the growing population requires adequate quantities of safe, nutritious and affordable food. Under these circumstances, the search for crops that can withstand environmental stresses while providing good nutritional value has become increasingly important. Millets are emerging as one of the promising solutions to these challenges. Millets are a diverse group of small-seeded cereals that have traditionally been cultivated in dry land and semi-arid regions of Asia and Africa. Important millets include pearl millet, finger millet, foxtail millet, little millet, kodo millet, barnyard millet and proso millet. Sorghum is also commonly discussed alongside millets because of its similar importance in dry land agriculture. These crops have been cultivated for centuries, but their importance is receiving renewed attention because of their ability to perform under difficult growing conditions and their valuable nutritional characteristics. The Food and Agriculture Organization has highlighted millets as crops capable of contributing to resilient and sustainable agrifood systems.

Millets as Climate-Resilient Crops

One of the greatest advantages of millets is their adaptation to harsh environmental conditions. Many millet species can be cultivated in areas receiving limited and uncertain rainfall. Their relatively short growing duration and physiological adaptations enable them to complete their life cycle under conditions where some water-demanding cereal crops may face greater production risks. ICAR research describes millet crops as climate-smart crops because of characteristics such as short duration, efficient water use, deep root systems and tolerance to high temperature and drought. These

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characteristics make them particularly relevant to rainfed agriculture. Millets can also grow in relatively poor soils and generally require fewer external inputs than many intensively cultivated crops. FAO notes that millets can grow under arid conditions with minimal inputs and can tolerate or resist several diseases and pests. Their cultivation can therefore contribute to agricultural systems that are more resilient to climate variability. Another important feature is their lower dependence on irrigation compared with many water-intensive cereal production systems. This makes millets particularly suitable for regions where groundwater resources are under pressure and rainfall is unpredictable. However, the water requirement of a crop varies according to species, variety, soil, climate and management practices, so millet should not be considered a completely drought-proof crop.

Nutritional Importance of Millets

The importance of millets is not limited to their performance in the field. They are also valuable from a nutritional perspective and are often referred to as "nutri-cereals."Millet grains provide carbohydrates, protein, dietary fibre, minerals and several vitamins. Their nutritional composition differs among species and varieties. For example, pearl millet is a useful source of protein, dietary fibre, iron and zinc, while finger millet is particularly valued for its mineral content, including calcium. Foxtail, little, kodo and other millets also contribute protein, fibre and micronutrients to the diet.

The presence of dietary fibre is another important characteristic. Whole-grain millets can contribute to satiety and healthy dietary patterns. FAO also reports that millets are generally gluten-free and can provide useful amounts of minerals, fibre and other nutrients.

However, the nutritional value of millet-based foods depends on the species, variety, processing method and preparation technique. Therefore, millets should be viewed as an important component of a diverse and balanced diet rather than as a single "super food" capable of meeting every nutritional requirement.

Major Millet Crops and Their Uses

India has a long tradition of millet cultivation and consumption. Different millet species are adapted to different agro-climatic conditions and have distinct food and fodder uses. Pearl millet (bajra) is widely cultivated in dry and semi-arid regions and is valued for its adaptability to heat and moisture stress. It is an important food and fodder crop. Finger millet (ragi) is especially important in parts of southern and central India. It is well known for its mineral content and is used in products such as flour, porridge, traditional foods and beverages. Foxtail millet, little millet, kodo millet, barnyard millet and proso millet are also valuable crops with potential for diversification of diets and farming systems. FAO recognizes these species as part of the broader diversity of millet crops cultivated across different regions. This diversity itself is an advantage. Instead of depending heavily on a small number of major cereal crops, farmers and consumers can benefit from a wider range of crops adapted to different environments.

Role in Sustainable Agriculture

Millets can contribute to sustainable agriculture in several ways. Their suitability for rainfed farming can reduce dependence on irrigation in appropriate production environments. Their tolerance to several environmental stresses can also reduce the risk associated with climate variability. Millet cultivation can additionally contribute to crop diversification. A diversified cropping system may provide farmers with greater flexibility in responding to changes in rainfall, temperature, market demand and pest pressure. Millets can also be incorporated into integrated farming systems involving livestock, pulses, oilseeds and other crops. Their crop residues can have value as livestock feed, although the quality and suitability of residues vary among crops and management systems. FAO emphasizes that millet

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cultivation can support soil protection and biodiversity, particularly in dryland environments. Maintaining crop diversity is also important for conserving genetic resources that may become increasingly valuable as agricultural conditions change.

Opportunities for Farmers and Rural Enterprises

The future of millets depends not only on production but also on the development of profitable value chains. Traditionally, many millet products have been consumed in simple forms such as flour, porridge and traditional preparations. Today, there is growing scope for processing millets into ready-to-cook and ready-to-eat products. Millet-based biscuits, snacks, breakfast products, flour blends, bakery products and other processed foods can create additional market opportunities. Better processing, packaging, branding and marketing can increase consumer acceptance and potentially improve returns to farmers. Farmer Producer Organizations (FPOs), self-help groups, rural entrepreneurs and small food-processing units can play an important role in developing local millet value chains. Such activities can generate employment while connecting producers with urban and institutional market. Recent ICAR work in Maharashtra also illustrates the potential of improved and biofortified pearl millet for improving both nutrition and farmer livelihoods.

Challenges in Millet Promotion

Despite their many advantages, millets face several challenges. One major issue is consumer preference. In many areas, rice and wheat have become dominant staples, while traditional millet consumption has declined. Another challenge is the availability of efficient processing technologies. Some millet grains require specialized cleaning, dehulling or processing before convenient household use. Lack of suitable machinery can increase labour requirements and processing costs. Farmers may also face problems related to quality seed availability, market access, fluctuating prices and limited technical knowledge. Therefore, simply encouraging farmers to grow more millets is not sufficient. A complete approach is needed that connects improved varieties, agronomic practices, processing, storage, and marketing and consumer awareness.

The Way Forward

The future of millets should be based on a combination of traditional knowledge and modern agricultural science. Research institutions need to continue developing varieties with improved yield, nutritional quality, stress tolerance and suitability for different production systems. Mechanization of sowing, harvesting and post-harvest processing can reduce labour requirements. Precision agriculture, improved weather information and digital advisory services can further support farmers in making timely decisions. There is also a need to strengthen millet-based value chains. Better packaging, attractive food products, quality standards and consumer education can increase demand. Public institutions, researchers, farmers, entrepreneurs and consumers all have a role to play in building a sustainable millet economy. The recognition given to millets through the United Nations International Year of Millets in 2023 helped bring global attention to their nutritional, environmental and economic potential. The FAO continues to identify millets as an important component of efforts toward more resilient and sustainable agrifood systems.

Conclusion

Millets may be small in size, but their potential for agriculture, nutrition and rural livelihoods is considerable. Their ability to tolerate drought and heat, perform under relatively low-input conditions and provide important nutrients makes them particularly relevant in an era of climate uncertainty. However, millets should not be viewed simply as a replacement for rice or wheat. Their greatest value lies in becoming part of a diversified agricultural and food system. Greater crop diversity, improved varieties, efficient production technologies, better

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processing and stronger markets can help farmers benefit from these resilient crops. The future of agriculture will require crops that can produce food while using natural resources responsibly. In this context, millets offer an important opportunity. By bringing together scientific innovation and traditional knowledge, millets can contribute to climate-resilient farming, nutritional security and sustainable rural development.

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The Role of Artificial Intelligence in Agriculture: Transforming Fields into Data-Driven

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Agriculture has always been a science of observation. For generations, farmers have read the sky for rain, judged soil by its colour and texture, and learned to spot a sick plant from its wilted leaf before the disease could spread. This inherited wisdom is invaluable, but it has limits a single farmer, however experienced, cannot monitor every square metre of a large field, predict a pest outbreak days before it happens, or process weather patterns across an entire district in real time. This is precisely where Artificial Intelligence (AI) is beginning to reshape the profession of farming itself.

AI, in simple terms, is the ability of computer systems to perform tasks that normally require human intelligence recognising patterns, making predictions, and improving through experience. When this capability is applied to agriculture, it becomes a powerful extension of the farmer's own senses and judgement. Instead of replacing traditional knowledge, AI supplements it with speed, scale, and precision that human observation alone cannot achieve. A drone can scan hundreds of acres in the time it takes a farmer to walk a single field. A machine-learning model can study years of rainfall and yield data to forecast a season's outcome. A smartphone camera, powered by a trained algorithm, can identify a leaf disease within seconds, long before the naked eye would notice trouble.

For a country like India, where more than half the workforce depends on agriculture and where landholdings are often small and fragmented, the promise of AI is not a luxury but a necessity. Climate variability, shrinking farm sizes, rising input costs, and labour shortages are pushing the sector toward a model where every drop of water, every gram of fertiliser, and every hour of labour must be used with greater efficiency. AI offers a pathway to exactly that kind of precision. This article attempts to walk through the many dimensions of this transformation from the basics of how AI works on a farm to the more advanced systems now being tested in research institutions, and finally to the challenges and future possibilities that will determine how meaningfully this technology reaches the average farmer's field.

Understanding How AI Actually Works on a Farm

Before looking at applications, it helps to understand what actually powers these systems. Most agricultural AI relies on three technologies working together. The first is machine learning, where algorithms are trained on large datasets say, thousands of images of healthy and diseased wheat leaves until the system learns to distinguish between them on its own. The second is computer vision, which allows machines to "see" and interpret images, whether captured by a drone, a satellite, or a mobile phone camera. The third is the Internet of Things (IoT), a network of sensors placed in soil, on machinery, or on animals that continuously feed real-time data into these AI models.

Across agricultural domains, AI capabilities function as system-level tools built on integrated data infrastructures rather than as isolated algorithms, and how well they perform often depends more on the

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consistency, resolution, and accuracy of the underlying data than on the sophistication of the algorithm itself. This is a crucial point for researchers to internalise: a brilliant model fed poor-quality or inconsistent field data will still produce unreliable recommendations. Good agronomic AI, therefore, is as much about disciplined data collection soil sampling protocols, calibrated sensors, and consistent georeferencing as it is about clever coding.

Precision Farming: Making Every Input Count

Precision agriculture is perhaps the most mature and widely discussed application of AI in farming today. Precision farming applies inputs variably across a field based on spatial data and predates modern AI, having grown out of GPS guidance, variable-rate technology, and soil mapping; AI now acts as the analytical layer that makes this system adaptive and increasingly self-executing. In practice, this means machine-learning models can update prescription maps in real time using satellite imagery, and computer-vision systems can flag disease symptoms in a crop days before they would be visible to a human scout.

The scale of benefit this can deliver is significant. Field deployments of such systems have shown yield increases of up to 40 percent alongside water-use reductions of around 30 percent in some documented cases. While such figures represent best-case outcomes rather than universal averages, they illustrate the ceiling of what is achievable when AI-guided input management is implemented well. Soil analysis is a good starting example: sensor networks combined with satellite imagery can now assess moisture content, salinity, and nutrient status of soil, allowing a farmer to apply fertiliser only where and when it is genuinely needed, rather than uniformly across an entire field. This targeted approach reduces both cost and environmental runoff, addressing two persistent concerns in Indian agronomy input inflation and groundwater depletion simultaneously.

Crop Health, Pest, and Disease Management

One of the most immediately useful applications for both researchers and farmers is AI-assisted disease and pest detection. Traditional scouting for pest infestations is labour-intensive and often reactive by the time symptoms are visually obvious, the infestation may already be advanced. AI-based image recognition changes this timeline. A photograph of a leaf, uploaded through a mobile app, can now be analysed against a trained model to identify the specific pathogen or pest at an early stage, often before visible spread across the field.

AI enables more accurate prediction of soil conditions, disease, pest and weed pressure, alongside more efficient resource management and better decision-making on the farm, and it plays an increasingly transformative role by using data and machine learning to optimise both crop and livestock production systems. This is not limited to private agri-tech platforms; public systems have adopted similar tools at scale. India's National Pest Surveillance System, for instance, uses AI and machine learning to detect crop issues so that timely intervention becomes possible, helping reduce production losses linked to changing climate patterns. This has been paired with AI-based analytics using field photographs for crop health assessment, along with satellite, weather, and soil-moisture data used to monitor the health of major crops such as rice and wheat.

For research scholars, this domain also opens rich avenues of inquiry comparing model accuracy across regional crop varieties, testing detection performance under varying light and humidity conditions, or building region-specific training datasets that account for local pest ecology rather than relying solely on global image repositories.

Irrigation, Weather Forecasting, and Climate Resilience

Water is arguably agriculture's most contested resource, and AI's contribution here may prove to be

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one of its most consequential. Predictive models trained on historical rainfall, soil moisture, and evapotranspiration data can now generate irrigation schedules tailored to a specific plot rather than a generic regional average. Combined with weather forecasting models, these systems help farmers decide not just how much water to apply, but exactly when before a heat spell, or in anticipation of rainfall that would otherwise be wasted alongside irrigation.

This capability becomes particularly important under climate stress. Erratic monsoon patterns, delayed onset of rains, and unseasonal weather events have made traditional almanac-based farming calendars less reliable. AI-driven weather advisory systems, by contrast, continuously recalibrate their forecasts as new data arrives, offering farmers a dynamic decision-support tool rather than a fixed seasonal guide. For smallholders working with thin margins, avoiding even one poorly timed irrigation or one missed pest-control window can make a meaningful difference to the season's outcome.

Yield Prediction and Market Intelligence

Beyond the field itself, AI is increasingly used to forecast yield and even anticipate market prices. By analysing satellite imagery alongside historical yield records, soil health data, and weather trends, models can generate fairly reliable estimates of expected output weeks or months before harvest. Such forecasting, combined with big-data analytics, is now also being used to help estimate output and detect pest and disease infestations at a broader, regional scale.

This has two practical benefits. First, it helps individual farmers plan storage, transport, and sale timing more intelligently, reducing the distress sales that often follow an unplanned glut. Second, at a policy level, it allows government agencies to anticipate supply shortfalls or surpluses and intervene through procurement or import decisions before a crisis develops. Yield estimation is also gradually being integrated into crop insurance mechanisms. In India, technology-based yield estimation is now used alongside conventional Crop Cutting Experiments to improve the accuracy of crop loss assessment and enable more timely insurance payouts to farmers.

AI as an Advisory Companion

Perhaps the most socially significant use of AI in Indian agriculture is not in the field but in the farmer's pocket. Extension services the traditional bridge between agricultural research and the farmer have long been understaffed relative to the scale of India's farming population. AI-powered chatbots and voice assistants are beginning to fill this gap, particularly for farmers who may not be comfortable with written text or formal English.

Kisan e-Mitra, a voice-enabled AI-powered chatbot launched in 2023, supports farmers with queries on major government schemes including PM Kisan Samman Nidhi, the Kisan Credit Card, and the Pradhan Mantri Fasal Bima Yojana, and operates in eleven regional languages. By December 2025, it had responded to more than ninety-three lakh farmer queries, handling over eight thousand queries a day. Complementing this, a separate WhatsApp-based chatbot has been introduced specifically to assist farmers with questions about the PMFBY crop insurance scheme.

At a broader policy level, the Union Budget for 2026–27 proposed Bharat-VISTAAR, a network that would connect interlinked databases such as AgriStack, India Meteorological Department data, and both state and private agro-content sources to improve agricultural decision-making. This multilingual AI tool is intended to integrate AgriStack portals with ICAR's package of agricultural practices, aiming to raise farm productivity, support better on-farm decisions, and lower risk through advisory support tailored to individual farmers. For a research scholar in agronomy, such platforms represent a fascinating convergence of agricultural science, linguistics, and

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public-policy design the success of these systems will depend as much on trust and usability as on the underlying model accuracy.

Livestock and Beyond

While crop-focused applications dominate the conversation, AI is equally relevant to livestock management. Biometric monitoring systems can now track an animal's movement patterns, feeding behaviour, and even early physiological signs of illness, allowing dairy and poultry farmers to intervene before a health issue affects the whole herd or flock. Such livestock biometric monitoring is increasingly being integrated alongside crop-focused tools as part of a broader move toward what is sometimes described as autonomous agronomy where AI-guided physical systems, not just analytical dashboards, begin to take on operational tasks in the field.

Why Adoption of AI Remains Uneven

No honest assessment of AI in agriculture can ignore the gap between technological promise and ground reality. A 2025 World Economic Forum report on AI in Indian agriculture pointed to numerous obstacles, including fragmented infrastructure, limited access to high-quality data, and affordability concerns among smallholder farmers. The report further noted that small landholdings inherently constrain scalability, mechanisation, and technology adoption, often confining marginal farmers to subsistence-oriented systems with low productivity and limited profitability.

This is echoed by researchers studying India's broader data ecosystem. Despite India generating substantial volumes of public agricultural data, AI adoption in farming remains limited and largely confined to pilot initiatives, reflecting a persistent gap between data availability and its practical application. Even where digital tools exist, limited digital literacy, high costs, poor data availability, and restricted access to digital infrastructure continue to deter large-scale adoption of agri-tech across the country. There is also a genuine cost barrier for high-end tools: drones, advanced sensors, and satellite subscriptions remain out of reach for many small and marginal farmers, even when the underlying algorithms are freely available. Encouragingly, researchers are now working to close this gap. Recent work on affordable precision agriculture has focused on low-cost, low-power edge AI and lightweight machine-learning models designed specifically for resource-constrained farming systems, using distributed sensing nodes that process data locally and reduce dependence on constant cloud connectivity. This kind of research sometimes referred to as TinyML could prove decisive in determining whether AI's benefits remain confined to large commercial farms or genuinely reach India's vast base of smallholders.

The Future of AI in Agriculture

The trajectory suggests that AI's role in agriculture will only deepen over the coming years, moving from advisory support toward genuine autonomy in certain operations. Digital twin models virtual replicas of a field that simulate outcomes of different management decisions before they are implemented on the ground are already being piloted as comprehensive decision-support tools. Autonomous machinery capable of initiating irrigation or spraying without direct human command is moving from research demonstration toward limited commercial use. Generative AI is also beginning to enter the picture, with early "AI agronomist" tools capable of answering complex, context-specific questions in natural language, potentially narrowing the extension-service gap even further than chatbots currently manage.

At the same time, the more meaningful future for a country like India may not lie in the most advanced systems, but in the most accessible ones. Small language models tailored to regional dialects, edge-AI devices that function without reliable internet connectivity, and low-cost sensor networks designed for one-acre plots rather than thousand-acre farms will likely determine how widely and how equitably

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this technology is adopted. Research institutions, including agricultural universities, have a critical role to play here: not merely in developing new algorithms, but in generating the region-specific, ground-truthed datasets on which any locally relevant AI system must be built. Collaboration between agronomists, computer scientists, and extension workers, rather than any single discipline working in isolation, is likely to determine how successfully this technology moves from pilot projects to everyday farming practice.

Conclusion

Artificial Intelligence is not a replacement for the farmer's judgement, nor a substitute for sound agronomic science it is a tool that extends both. From identifying a diseased leaf before it spreads, to scheduling irrigation with precision, to answering a farmer's question in her own language at any hour of the day, AI is quietly embedding itself into the everyday decisions that determine a season's success or failure. The technology's promise is real, but so are the barriers of cost, connectivity, and data quality that stand between a research prototype and a working tool in a farmer's hand. For researchers in agronomy, this is perhaps the most exciting frontier of all not simply building smarter algorithms, but ensuring that intelligence, once artificial, becomes genuinely useful, affordable, and trustworthy for the people who feed the nation.

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Biotechnology and Genetic engineering in Mushrooms for Improved Yield and Bioactive Compounds

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Mushrooms have evolved from a culinary garnish into a vital contributor to global food security, medicine, and environmental sustainability. As the world population approaches an estimated 8.5 billion by 2030, conventional cultivation and breeding methods are proving too slow to meet rising demand for both yield and the bioactive compounds mushrooms are prized for. This article surveys how biotechnology and genetic engineering are accelerating mushroom improvement across four complementary fronts. Marker-assisted selection uses DNA markers to speed up conventional breeding for traits such as cap colour, texture, and disease resistance. Protoplast fusion bypasses natural mating barriers, allowing genetic material to be exchanged between strains and even species that cannot cross conventionally. CRISPR-Cas9 gene editing offers unprecedented precision, enabling researchers to knock out or fine-tune specific genes governing growth, stress tolerance and metabolite production, while RNA interference provides a reversible, dial-down approach to silencing target genes. Together, these tools are not only boosting yield but also enhancing the production of medicinally valuable polysaccharides, phenolics, and terpenoids that occur only in small quantities in nature. The article also considers the ethical, regulatory and technical challenges accompanying these advances including ecological risk, biosafety oversight, and the practical limits of current transformation efficiencies and looks ahead to emerging tools such as single-cell transcriptomics and pathway engineering. Taken together, these developments position mushrooms as a strategic frontier for sustainable, science-driven innovation in food and medicine.

Introduction

Mushrooms are fleshy, visible fungi that do not contain chlorophyll and obtain nutrients through a heterotrophic mode of nutrition. The term "mushroom" commonly refers to various fungal species within the Basidiomycetes and Ascomycetes groups. Chang *et al*. (1999) described a mushroom as a macroscopic fungus with a distinct fruiting body—either aboveground or underground, that is large enough to be seen and collected by hand. These organisms typically appear in environments rich in organic matter, such as humus-laden soils, damp wood, or animal waste, often emerging after rain or temperature changes and then disappearing within hours or days, leaving behind only their mycelium (Chang *et al.,* 1999). Humans have used mushrooms since ancient times, with records of use extending as far back as 5000 BCE. Approximately 2,000 edible mushroom species are known worldwide. For many cultures and tribal societies, certain mushrooms have long held ceremonial importance; historical sources note that the Romans attributed extraordinary powers to some species, including enhanced strength and supernatural abilities. Beyond cultural uses, mushrooms serve as food, tonics, and medicines. Regular consumption is associated with better health and vitality, and mushrooms are valued for their nutritional and bioactive profile containing functional proteins, vitamins, minerals, low levels of calories and carbohydrates, growth-promoting compounds, and substantial dietary fiber which

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supports their classification as functional. Mushroom cultivation and use also present economic opportunities: they can drive inclusive growth, support a non-green agricultural revolution in less developed regions, and create tangible socio-economic benefits at local, national, and regional levels (Nagaraju, 2023).

Why Mushrooms Need a Biotech Boost?

Traditional mushroom cultivation has served the industry well, but it remains a fundamentally slow process (Sanchez, 2004). Selecting superior strains through conventional means successive rounds of crossing, cultivation, and phenotypic observation can require years of effort for comparatively modest genetic gains. Mushroom yield, meanwhile, is governed by a complex interplay of biological factors, including the rate of mycelial expansion, the efficiency of primordium initiation, and the fungus's capacity to withstand heat stress, contamination, and other adverse growing conditions (Nagaraju, 2023). The advent of modern "omics" technologies transcriptomics, proteomics, and genomics has enabled researchers to identify the specific genes underlying these traits with far greater accuracy (Arshadi *et al.,* 2023), while gene-editing platforms such as CRISPR-Cas9 now allow these genes to be modified directly, eliminating the reliance on chance recombination inherent to conventional breeding (Tarafder *et al.,* 2024).

Biotechnology is likewise transforming the cultivation process itself. Engineered strains have demonstrated improved substrate-utilisation efficiency, broader thermal tolerance, and enhanced resistance to contaminating moulds and bacteria (Konka and Khanna, 2022), collectively reducing production losses and improving the reliability of commercial-scale operations. Classical breeding and hybridisation techniques have not been rendered obsolete; rather, they continue to complement molecular approaches, together enabling the development of strains tailored to specific climatic conditions and market requirements (Liu *et al.,* 2026).

The Biotechnology Toolkit

Four main biotechnological strategies are driving this mushroom makeover: marker-assisted selection, protoplast fusion, CRISPR-Cas9 gene editing, and RNA interference. Each works differently, but all aim at the same target better yield and richer bioactive content (Table 1).

Biotechnological Strategy	Core Mechanisms	Target Improvements
Marker-Assisted Selection	Employs specific DNA markers to streamline traditional breeding cycles	Cap coloration & total crop yield
Protoplast Fusion	Fuses somatic cells between naturally incompatible fungal strains	Novel hybrid development
CRISPR-Cas9 Gene Editing	Enables targeted modification or knockouts of specific functional genes	Growth kinetics, stress resistance & metabolite output
RNA Interference (RNAi)	Transcriptional/post-transcriptional gene silencing	Morphological development & environmental stress tolerance

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Table 1: Four complementary biotechnological routes converge on higher yield and more bioactive compounds.

Marker-Assisted Selection: Breeding with a Roadmap

Rather than crossing strains and relying on chance outcomes, breeders now employ DNA "markers" short, identifiable sequences linked to a desirable trait to select appropriate parent strains from the outset. Specialized software tools translate this marker data into genetic linkage maps, allowing breeders to pinpoint precisely where useful genes are located within the genome (Foulongne-Oriol *et al.,* 2012). This approach is particularly effective for simple, single-gene traits: breeders, for example, combined the mechanical-harvest-friendly texture characteristic of off-white button mushroom strains with the superior colour-retention properties of white strains to develop hybrids that captured the advantages of both. DNA fingerprinting has also proven valuable in enabling spawn producers to protect their strains as intellectual property and has been employed to introgress traits such as brown cap pigmentation and sporeless fruiting bodies from wild relatives into commercial *Pleurotus* hybrids. More complex traits including yield, disease resistance and overall quality are typically governed by multiple genes acting in concert, a phenomenon captured by the concept of quantitative trait loci (QTLs). Researchers have successfully mapped QTLs associated with diseases such as bacterial blotch and dry bubble, using this information to breed hardier, more resilient hybrids. Notably, *Agaricus bisporus*, the common button mushroom, retains considerable untapped genetic diversity within its wild populations, suggesting substantial scope to broaden the cultivated gene pool through conventional breeding strategies alone, without recourse to genetic modification (Loftus, 2000).

Protoplast Fusion: Matchmaking Between Species

Certain genetically advantageous combinations cannot be achieved through conventional mating alone. Protoplast fusion circumvents this limitation by removing the rigid fungal cell wall and directly merging the resulting protoplasts of two distinct strains or, in some cases, two distinct species. This non-conventional breeding technique has proven particularly valuable for generating novel hybrids among Basidiomycete mushrooms. While fusion is generally most successful between closely related strains, recombination between more distantly related organisms can substantially broaden the accessible gene pool. Related methodologies, including the uptake of isolated organelles and DNA-mediated transformation, have further advanced our understanding of fungal molecular biology and established viable pathways for the commercial-scale production of valuable medicinal compounds (Singh *et al.,* 2007).

CRISPR-Cas9: The Precision Gene Editor

If marker-assisted selection provides a roadmap and protoplast fusion facilitates matchmaking between strains, CRISPR-Cas9 functions as a molecular scalpel. This gene-editing system, adapted from a naturally occurring bacterial immune mechanism, enables researchers to deactivate or precisely fine-tune individual genes with remarkable specificity (Kumar *et al.,* 2021). The process begins with the design of a "guide RNA" engineered to match a target gene sequence (Chen *et al.,* 2022); this guide directs the Cas9 enzyme to the corresponding site in the genome, where it introduces a precise cleavage in the DNA. During the subsequent repair process, small insertions or deletions termed indels frequently arise, permanently disrupting the function of the targeted gene. Methodologies originally developed for guide RNA design in mammalian systems, with particular attention to sequence specificity and the protospacer adjacent motif (PAM), have since been successfully adapted for application in fungal system. In practice,

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researchers employ CRISPR-mediated knockouts as an investigative tool: by disabling a candidate gene and observing the resulting phenotypic changes, they can establish causal links between genotype and function (Figure 1). This approach has enabled scientists to confirm the genes responsible for fruiting-body formation (Wang *et al.,* 2020), the biosynthesis of pharmacologically significant bioactive compounds, and stress-response pathways. Beyond fundamental research applications, this technology is increasingly being deployed to engineer practical improvements in cultivated strains for instance, by disabling genes associated with disease susceptibility, or by modifying secondary-metabolite pathways to enhance nutritional or pharmaceutical value (Arshadi *et al.,* 2023).

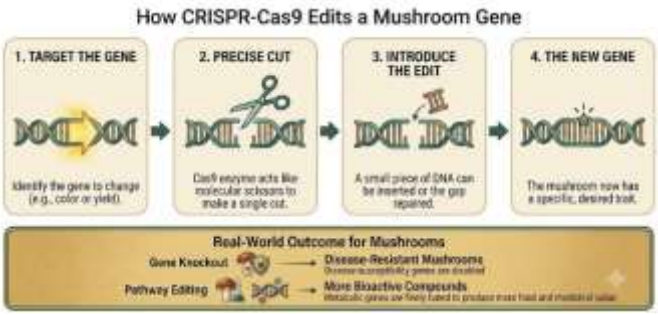

Figure 1: Editing Mushroom Genes with CRISPR-Cas9

RNA Interference: Turning the Volume Down, Not Off

Where CRISPR permanently disables a gene, RNA interference (RNAi) works more like a dimmer switch it silences a gene's activity without altering the underlying DNA. A transformation protocol developed for the edible mushroom *Grifola frondosa* demonstrated that RNAi can reduce the expression of a target gene enough to change developmental outcomes, with real potential to enhance both yield and quality (Sato *et al.,* 2015). Direct proof that RNAi boosts mushroom yield is still limited, but evidence from other fungi suggests it can improve productivity and stress tolerance both highly desirable for commercial growers (Thipe *et al.,* 2021). Because RNAi interventions can be so precisely targeted, many researchers see it as a promising route to farming that is both more efficient and more sustainable.

Biochemical compounds of mushrooms

Mushrooms are natural chemists. They produce polysaccharides, phenolic compounds, terpenoids, peptides, and enzymes with antioxidant, antimicrobial, anticancer, and immune-boosting properties. The catch is that many of these valuable compounds occur only in tiny natural quantities. Biotechnology helps close that gap in two main ways: by identifying the genes and metabolic pathways behind compound production, and by boosting the activity of the enzymes that make them. Transcriptomic and metabolomic studies are proving especially useful for understanding exactly how growing conditions shape the final chemical profile of a mushroom crop. Metabolic engineering takes this a step further, allowing scientists to redirect a fungus's internal chemistry toward a specific valuable product, an approach that matters enormously for medicinal mushrooms, where market demand for bioactive metabolites already outstrips what nature alone can supply. The same techniques can even coax mushrooms into producing entirely new compounds through pathway modification and the insertion of genes from other organisms.

Ethics and Regulation

Genetically modified mushrooms raise the same kinds of questions as any genetically engineered organism. Could altered strains disturb natural fungal communities, become invasive, or pass modified genes into wild populations. The growing accessibility of tools like CRISPR-Cas9 has heightened concern about inadequate regulation and potential misuse, while the long-term effects of genetic changes remain genuinely uncertain. There are also questions of fairness who owns a modified strain, who benefits from it, and how traditional knowledge and local communities are respected in the process. None of these rules out the technology;

it simply underlines why science-based regulation and careful, ongoing monitoring are essential companions to innovation (Niego *et al.,* 2021).

For all its promise, mushroom biotechnology still faces real obstacles. Fungal genetics are complex, and for many species scientists simply don't yet have enough genomic data to work with. Techniques such as protoplast fusion, *Agrobacterium*-mediated gene transfer, and CRISPR editing remain inefficient in many mushroom species compared with better-studied plants. Environmental variables temperature, humidity, substrate quality, contamination can undercut even a well-engineered strain, and boosting one trait, such as yield, sometimes comes at the cost of another, such as flavour or disease resistance. Add to this the high cost of research, the need for specialised expertise, public wariness about genetically modified food, and strict biosafety rules, and it's clear that turning a promising lab result into a commercial crop still takes real time and investment.

What's Next for Mushroom Science

The pace of discovery is accelerating. Whole-genome and transcriptome sequencing are steadily revealing the genetic circuitry that governs mushroom growth including master regulators like the Roc1 transcription factor, which helps orchestrate fruiting-body formation in Basidiomycota. The next wave of tools more advanced CRISPR platforms, single-cell and spatial transcriptomics, and smarter functional screens promises to connect genes to traits faster than ever, speeding the development of strains with higher yield, greater stress tolerance, and richer metabolite profiles. Genetics is also shaping more sustainable ways to grow mushrooms. Research into commercially vital species like Agaricus bisporus has already identified genes linked to disease resistance and better agronomic performance, informing breeding strategies that cut losses and resource use. Some of the most exciting ideas look beyond the mushroom itself for example, capturing the carbon dioxide produced in mushroom houses to help grow companion crops such as lettuce, pairing genetic advances with circular, systems-level thinking about sustainable farming.

Conclusion

Biotechnology and genetic engineering are quietly transforming mushroom farming from a slow, traditional craft into a precise, science-driven industry. Tools like CRISPR-Cas9 and RNA interference are already delivering better yields and stronger disease resistance, while system-wide omics research is mapping the biosynthetic pathways behind valuable medicinal compounds. Progress in gene cloning, QTL mapping, and transformation methods is steadily closing the gap between mushroom science and the more mature field of plant crop breeding, paving the way for robust, high-yielding commercial hybrids. Arshadi et al. even report that modern overproduction strategies can boost desired bioactive compound yields up to fourfold - a real solution to the supply bottlenecks that have long limited clinical research and commercial use. As Fan et al. note, these advances are also helping the global mushroom industry turn agricultural waste into high-value functional foods and therapeutics. The mushroom, once a humble forest find, is emerging as one of biotechnology's most promising ingredients for a healthier, more food-secure future.

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The Push-Up and Pull-Back Theory in Administration: *Two Facets of the Same Coin*

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The **"Push-Up and Pull-Back Theory"** is a common but often overlooked phenomenon in administration. It represents two contradictory approaches operating simultaneously—encouraging an officer to work hard while, at the same time, creating obstacles that discourage him from actually doing so. **"Work hard. Take initiative. Be proactive. Deliver results."** These are familiar words in almost every administrative organization. Senior officers often encourage their subordinates to work harder, take responsibility, show initiative and contribute beyond their routine duties. Employees are told that the institute/organization needs people who are willing to think, act and make things happen. But there is another side to the story. Sometimes, the very employee who responds to this encouragement and genuinely tries to work is subsequently confronted by a maze of procedures, approvals, repeated queries, file movements, documentation and delays. The employee is pushed to work hard, but when he actually starts working, the system begins to pull him back. This can be described as the **"Push-Up and Pull-Back Theory in Administration."** It is not a formal administrative theory in the conventional academic sense. Rather, it is a practical way of describing a contradiction that many employees experience: **the organization demands initiative but does not always create an environment in which initiative can succeed.** The phenomenon can be understood as **two facets of the same coin**—one side pushes the employee forward, while the other side pulls him backward.

I. The Push-Up — "Work Hard and Take Initiative"

Every institution/organization needs motivated employees. No institution can progress if its staff merely follow routine instructions and wait for someone else to take responsibility. Therefore, senior authorities quite rightly encourage employees to take initiative. They ask officers to identify problems, develop proposals, improve systems, undertake new activities and deliver better results. An enthusiastic officer responds positively. He may think: **"If I have the authority and responsibility to do something useful, why should I wait?"** He prepares a proposal. He consults colleagues. He collects information. He prepares estimates. He writes notes. He seeks approval from the appropriate authority. He may even work beyond normal hours because he genuinely wants the work to succeed. At this stage, the employee is **"pushed up."** He is motivated by professional pride, recognition, responsibility and the satisfaction of accomplishing something meaningful. This kind of internal motivation is particularly important in scientific community. People often enter in institution/organization with the desire to contribute to society, improve institutions and make a difference. But the real test begins when the employee moves from **intention to action**. The officer who was told to take initiative now submits a proposal for approval.

And then—**the file starts moving.** One approval is required. Then another. Then a clarification.

Then another clarification. The proposal is returned for modification. A new document is requested. Another section is asked to comment. A committee may be required. The matter is discussed again. The employee responds. The file moves again. And the process continues.

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The enthusiasm that existed at the beginning slowly starts disappearing. This is where the **"Pull-Back"** begins.

II. The Pull-Back — When the System Discourages the Worker

Administration requires rules. Procedures are necessary to ensure accountability, transparency, financial discipline and fairness. The problem begins when procedures become an end in themselves rather than a means of achieving the organization's purpose. This is commonly associated with **"red tape"**—rules and procedures that impose compliance burdens without making a meaningful contribution to the intended objective. Research has found that red tape can have negative effects on both organizational performance and employee outcomes. Imagine an officer who has been asked to improve a particular activity. He takes the instruction seriously. He prepares a plan. He seeks approval. Instead of being facilitated, however, he encounters procedural obstacles. The message he receives may not be explicitly stated, but the system effectively tells him:

"Yes, you should work—but not so easily."

This is the paradox. The organization says: **"Take initiative."** But the process says: **"Wait for approval."** The organization says: **"Complete the work quickly."** But the system says: **"Follow every procedure, even when some of them add little value."** The organization says: **"Be responsible."** But the employee discovers that responsibility can mean additional paperwork, additional questions, additional scrutiny and additional personal risk. Administrative delay can have consequences beyond simply wasting time. Research has linked administrative delay and red tape with reduced organizational service capacity and poorer performance. The psychological effect on the employee can be even more damaging.

Initially, the officer thinks: **"I can make a difference."** After repeated obstacles, the thought becomes: **"Why should I bother?"** Eventually it may become: **"It is safer not to take initiative."** And finally: **"If I do nothing, nothing happens to me."** This is where an enthusiastic employee begins to change. He may stop proposing new ideas. He may stop volunteering. He may stop taking responsibility beyond his basic duties. He may avoid decisions. He may wait for written instructions. He may learn to protect himself rather than improve the organization. The tragedy is that the employee did not necessarily begin his career with this attitude.

The system may have taught him to become passive.

Recent research involving more than 117,000 Australian public-service employees found that red tape can increase work-related stress and negatively affect organizational commitment. Similarly, research on public servants has found that bureaucracy can frustrate employees' sense of autonomy and competence—two important psychological foundations of intrinsic motivation.

III. The Salary Paradox

There is another important element in this phenomenon. In many administrative systems, the employee's basic salary does not automatically change according to how much initiative he takes. Whether an officer works exceptionally hard or simply performs the minimum required duties, the monthly salary generally arrives. This creates a powerful psychological comparison:

Hard work:

More responsibility + more complications + more scrutiny + more stress

Doing the minimum:

Less responsibility + fewer complications + less personal risk + same salary If this pattern continues for years, the rational response for some employees may become:

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"Why should I create problems for myself? Whether I work hard or remain quiet, I will receive my salary."

This is perhaps the most dangerous stage of the Push-Up and Pull-Back cycle. The organization has not only failed to motivate the employee; it has unintentionally taught him that **initiative has a cost but inactivity has very little cost.** That lesson can permanently change workplace culture. One motivated employee becomes cautious. Another observes him. A younger employee learns from older colleagues. Soon, a culture develops in which people say: **"Don't take unnecessary responsibility." "Let the file remain where it is." "Why should you take the risk?" "Just do what is required."** And gradually, an institution that once wanted innovative and hardworking employees becomes an institution where employees learn to survive rather than perform.

IV. Breaking the Cycle — Push Forward, Don't Pull Back

The solution is not to remove all administrative procedures. Rules are essential. Approvals are also necessary along with, accountability and documentation protect institutions from misuse and arbitrary decisions.The real challenge is to distinguish between **necessary administration and unnecessary obstruction**. A healthy administrative system should ask a simple question: **"Does this procedure help us achieve the objective, or does it merely delay the objective?"** If a procedure improves accountability, it should remain. If it protects public resources, it should remain. If it prevents misuse, it should remain. But if a procedure exists only because **"this is how it has always been done,"** it deserves to be questioned.

The objective of administration should not be to make employees work harder merely by giving them more procedures. The objective should be to **make it easier for good employees to do good work responsibly.** This requires a change in administrative thinking.

1. Encourage initiative—and support it

If a senior officer asks an employee to take initiative, the employee should receive reasonable support when he acts. Encouragement without support creates frustration.

2. Simplify approvals

Where multiple levels of approval are not genuinely necessary, decision-making should be delegated to the appropriate level. An employee should not spend weeks obtaining approvals for a task that could responsibly be decided in days.

3. Reward responsible initiative

Employees who take calculated, responsible initiative should not feel that they will be punished merely because the outcome is imperfect. A culture that punishes every mistake eventually produces employees who avoid decisions.

4. Distinguish negligence from genuine effort

An officer who deliberately ignores rules should be held accountable. But an officer who makes a reasonable decision in good faith while trying to achieve an organizational objective should be treated differently.

5. Measure outcomes, not paperwork

An employee should not be considered productive merely because he generates files, notes, meetings and reports. The more important question is: **What was actually achieved?**

6. Remove unnecessary administrative burdens

Research suggests that excessive administrative burdens can consume resources that employees need for meaningful work and can undermine motivation and commitment. Therefore, organizations should periodically review their own procedures and ask:

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What can be removed? What can be simplified? What can be delegated? What can be decided faster?

V. The Real Cost of Pulling Back

The cost of administrative obstruction is not merely a delayed file. It can be the loss of an employee's **enthusiasm**. It can be the loss of **initiative**. It can be the loss of **innovation**. It can be the loss of **institutional commitment**. And ultimately, it can be the loss of an employee who once genuinely wanted to contribute. The most dangerous outcome is not an employee who refuses to work. It is an employee who **used to want to work but has learned that working hard is not worth the trouble.** That transformation may happen slowly and silently. There may be no formal complaint. No resignation. No confrontation. The employee simply becomes quiet. He stops suggesting. He stops asking. He stops trying. He does exactly what is necessary—and nothing more. And at the end of every month, the salary arrives exactly as it did when he was enthusiastic. That is the administrative tragedy captured by the **Push-Up and Pull-Back Theory.**

Fig.1 Pictographic representation of The Push-Up and Pull-Back Theory in Administration

VII. Conclusion: Don't Just Push Employees—Remove What Pulls Them Back

Good administration should push employees forward. But it must not simultaneously pull them backward. Motivation without empowerment is frustration. Responsibility without authority is a burden. Initiative without support is discouragement. Accountability without reasonable freedom is risk avoidance. And hard work without recognition or facilitation eventually becomes a lesson in passivity. The purpose of administration should therefore be more than telling employees to work hard. It should create an environment where working hard actually produces results. The best leader is not necessarily the one who constantly tells employees to do more. The best leader is the one who asks: "What is stopping my people from doing their best work—and what can I remove?" That is the difference between simply pushing people and genuinely enabling people. A healthy organization should therefore follow a simple principle: Push-Up, but do not Pull-Back. Encourage initiative. Remove unnecessary barriers. Trust responsible employees. Simplify procedures. Facilitate decisions. Reward results.

Because when an organization repeatedly pulls back the people it asks to move forward, eventually those people stop moving. And once an employee learns that silence is safer than initiative, the organization may continue paying the salary—but it may have already lost the worker's most valuable asset.

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Cucumber Cultivation Under Protected Condition

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Cucumber (*Cucumis sativus* L.) is an important vegetable crop belongs to the family cucurbitaceae and is widely cultivated for its high tender fruits. The crop is valued for its high water content, refreshing taste, low calorie value and contribution of vitamins, minerals and bioactive compounds to the human diet. Cucumber consumed mainly as a fresh vegetable, salad and pickle, and its demand increasing with the growing preference for fresh and healthy foods. Protected cultivation has emerged as an effective approach for producing high quality cucumber throughout the year, particularly under protected conditions were open-field production is easily affected by unfavourable weather, pest and disease incidence and fluctuations in temperature and humidity.

Structures such as polyhouses and naturally ventilated greenhouses provide a controlled environment that allows better management of temperature, relative humidity, irrigation, nutrition and plant protection. Cucumber is particularly suitable for protected cultivation because of its rapid growth, high yield potential and suitability for vertical training systems.

The increasing concern regarding excessive use of synthetic fertilizers and pesticides encouraged the development of organic production practices. Organic cucumber cultivation emphasizes the use of farm-derived and biologically based inputs such as compost, farmyard manure, vermicompost, enriched organic manures, biofertilizers, botanical preparations and natural nutrient sources. In recent years, the international demand for organically produced vegetables has increased due to growing consumer awareness of food safety, environmental sustainability and healthy eating. Organic cucumber has gained attention in export markets because it is produced using organic production practices that restrict the use of synthetic fertilizers and pesticides. Consumers in many developed countries are increasingly willing to purchase vegetables produced with environmentally responsible methods.

Cultivation of organic cucumber under protected condition

Nursery

Seedlings are raised in plastic pro-trays having 1.5-inch cell size using a soilless growing medium during the months of December or January. The growing medium in the plastic pro-trays consists of cocopeat and well-decomposed organic manure. Well decomposed organic manure provide nutrients to the seedlings while cocopeat helps retain moisture. The compost may be prepared in any one of the given combination,

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Cocopeat: vermicompost -3:1

Soil: cocopeat: vermicompost - 1:1:1

Soil: cocopeat: compost - 1:1:1

Cocopeat: vermicompost: rice husk - 2:1:1

Raising of Nursery

Cucumber seeds requires 26-28℃. For germination a temperature of approximately 25℃ is maintained until root establishment, followed by 21℃ at night and 23-25℃ during the day. Under the protected conditions, an average temperature of about 21℃ is maintained. The seedlings become suitable for transplanting at around 42 days after sowing. The recommended seed rate is approximately 500g ha^{-1}.

Growing Bed Preparations

Seedlings are transplanted on raised beds arranged in a single-row planting system. The beds are maintained at approximately 90 cm width, with a 30 cm walking space between beds.

Media

The growing medium should have a high water-holding capacity, low salinity, good drainage and adequate aeration. In growing medium pH should be maintained between 5.5 to 6.5. It should also be free from pathogens and weed seeds. Organic growing medium includes farmyard manure, vermicompost, cocopeat, neem cake, rice husk, groundnut shell and combinations of these materials mixed with soil.

Maintenance of Relative Humidity

Relative humidity plays an important role in cucumber growth, flowering, fruit development and disease management under protected cultivation. An RH of about 60–80% is highly suitable for cucumber, with approximately 70–75% RH considered favourable for maintaining good plant growth and fruit development. However RH remains above 80–85% for prolonged periods, can increase the risk of fungal diseases such as powdery mildew and downy mildew. Conversely, excessive low humidity can increase transpiration and cause water stress, particularly during periods of high temperature.

Spacing

Plant to plant distance – 40cm

Row to row distance – 100cm

Mulching

Organic mulching in protected cultivation refers to the practice of covering the soil surface inside a greenhouse or net house with biodegradable materials such as straw, dried leaves, compost, or crop residues. This practice helps conserve soil moisture, regulate soil temperature, suppress weed growth, reduce soil erosion, and improve soil health as the organic materials decompose.

Advantages of Mulching

Training and Pruning

Pruning is an important management practice in protected cucumber, particularly for plants with vigorous vine growth. It helps to maintain a proper balance between vegetative shoots and leaves. Pruning can improve fruit size and average fruit weight while reducing the formation of small or unmarketable fruits. In trained plants, the main stem and selected lateral shoots are retained, while excess lateral growth is removed during the early stages of development. This practice also improves light

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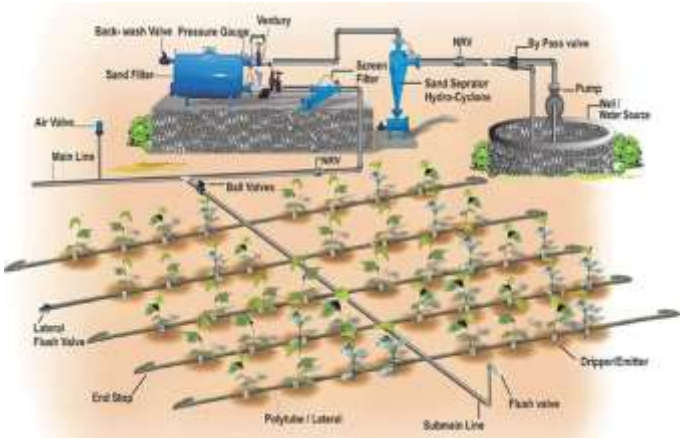
penetration, air circulation, and ease of crop management. During pruning, secondary branches developing after the eighth node can be retained to support continued plant growth. This pruning method facilitates easy training of the cucumber vines using a nylon net trellis or strings with vine clips. Misshapen, poorly developed, or unpollinated fruits should be removed promptly to direct the plant resources towards healthy and marketable fruits.

Trellising

Trellising is an important cultural practice in protected cucumber production because it supports the vigorous climbing growth of the crop and improves the use of vertical space. In a protected structure, plants are commonly trained upward using strong strings or ropes attached to overhead wires. The main stem is guided along the string and secured gently at regular intervals to prevent bending or breakage. Unwanted lateral shoots and older leaves may be removed selectively to maintain an open canopy and improve light penetration and air circulation. Proper trellising also keeps fruits away from the ground, promotes uniform fruit development and improves fruit quality. It facilitates efficient irrigation, crop monitoring, pest and disease management, and harvesting while making better use of the available protected-cultivation area.

Irrigation

Drip irrigation is preferred because it delivers water directly to the root zone, minimizes evaporation and reduces the risk of foliar diseases. During the initial growth stage, approximately 1–2 litre of water per plant per day may be supplied, while water requirements can increase to about 2–4 litre per plant per day during flowering, fruit development and harvesting, depending on crop age, weather conditions, growing medium and greenhouse environment. Irrigation should preferably be scheduled according to soil or growing-media moisture and crop demand rather than following a fixed schedule. Frequent, smaller irrigations are generally more effective than heavy applications, particularly in sandy or well-drained media. Excess irrigation should be avoided because it can reduce root aeration, encourage nutrient leaching and favour root diseases.



Layout For Drip Irrigation System

Nutrient Management

Before planting, well-decomposed farmyard manure or compost at 20–25 t/ha, vermicompost at 2–5 t/ha, and neem cake at 1–2 t/ha can be added to the raised beds. Biofertilizers such as *Azotobacter* or *Azospirillum* and phosphate-solubilizing bacteria (PSB) may be applied at 2–5 kg/ha each by mixing them with compost and placing the mixture near the root zone. For biological protection against soil-borne diseases, *Trichoderma harzianum* at 2–5 kg/ ha can be mixed with the growing medium. During crop

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growth, 5% vermiwash or 3% Panchagavya can be sprayed on the foliage at 10–15-day intervals to improve plant growth and nutrient supply.

Weed Management

Weeds should be controlled manually or mechanically. Organic mulches such as suitable plant residues can reduce weed growth and conserve soil moisture, provided they are free from contaminants and compatible with organic standards.

Pest Management

Aphids can be managed by spraying 3% neem oil (30 ml/l water) with 0.5–1 ml/l mild soap or suitable organic wetting agent, or by applying 5% neem seed kernel extract (NSKE). Whiteflies can be monitored and reduced using yellow sticky traps at 10–12 traps per 1000 m², along with azadirachtin 1% at 5 ml/l water or 3% neem oil. Thrips can be managed with blue sticky traps at 10–12 traps per 1000 m², supplemented with 3% neem oil or azadirachtin 1% at 3–5 ml/L water. Red spider mites can be suppressed using 3% neem oil or azadirachtin 1% at 5 ml/L water. For leaf miners, severely affected leaves should be removed and destroyed, yellow sticky traps can be installed at 10–12 traps per 1000 m², and 3% neem oil may be applied when required. Cucumber fruit fly can be managed by collecting and destroying fallen or infested fruits and installing fruit-fly traps at approximately 4 traps per acre, along with 3% neem oil application. Caterpillars and fruit borers can be controlled using *Bacillus thuringiensis* (Bt) at 2 g/l water or 5% NSKE. Melon and cucumber beetles can be managed through hand collection of adults, removal of crop residues and weeds, maintenance of greenhouse sanitation and application of permitted neem-based products.

Disease Management

Seeds can be treated with *Trichoderma viride* at 4 g/kg seed or *Pseudomonas fluorescens* at 10 g /kg seed to suppress seed and soil-borne pathogens. Powdery mildew can be managed by applying 5% neem seed kernel extract or 3% neem oil, with two applications at 10-day intervals beginning at the early stage of disease development. A *Pseudomonas fluorescens*-based biological preparation can also be used preventively at 250–500 g per 100 litre of spray solution, while 1–2 kg per 100 litre may be used when disease pressure is high, subject to the product recommendation. These treatments should be supported by good greenhouse management practices, including adequate ventilation, proper plant spacing, controlled irrigation, timely removal of infected plant parts and regular crop inspection, thereby limiting disease development and promoting healthy cucumber growth.

Harvest

The first harvest is usually obtained 35–40 days after transplanting in gynoecious slicing cultivars, while monoecious cultivars may require about 45–50 days. Harvesting is a continuous process, and fruits are commonly picked at about two day intervals to maintain desirable size and quality. The fruits should be handled carefully during harvesting and protected from bruising, dehydration and moisture loss, as their skin is tender and easily damaged. Under good crop management, gynoecious cucumber cultivars can provide multiple harvests over an extended crop period, with high yields achievable under favourable growing conditions.

Future Prospectives

Protected structures can provide better control over temperature, humidity, irrigation and crop nutrition, thereby supporting consistent production and reducing losses caused by adverse weather. Future efforts should emphasize the use of compost, vermicompost, biofertilizers, beneficial microorganisms and plant-based bio-stimulants for maintaining soil fertility and improving crop performance. Greater adoption of biological pest and disease management, efficient drip irrigation, suitable organic nutrient formulations and improved parthenocarpic or gynoecious hybrids can further enhance productivity. Research on postharvest

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treatments, eco-friendly packaging, extended shelf life and export-quality fruit production will also create new market opportunities. Integration of smart greenhouse technologies for monitoring environmental conditions and crop requirements can improve resource-use efficiency and profitability. Thus, organic cucumber production under protected cultivation can become an important approach for sustainable vegetable production, premium markets and future export-oriented farming.

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Designing Crop Canopies for Better Sunlight Use and Higher Yields

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Sunlight is the ultimate source of energy for crop growth, but the ability of plants to capture and utilize this energy depends largely on canopy architecture. Canopy architecture refers to the arrangement of leaves, stems, and branches within a crop stand. An efficient canopy allows maximum interception of sunlight while ensuring its uniform distribution throughout the plant population. Traits such as leaf angle, leaf area, plant height, and plant density influence photosynthesis, water-use efficiency, nutrient uptake, and crop yield. Modern crop varieties and precision farming technologies increasingly focus on optimizing canopy structure to improve productivity under changing climatic conditions. Understanding canopy architecture helps farmers adopt better crop management practices, maintain healthy crop stands, reduce pest and disease incidence, and enhance resource-use efficiency. Improved canopy management offers a practical pathway to achieve higher yields and sustainable agricultural production.

Sunlight is the primary energy source that drives crop growth and productivity. Through photosynthesis, plants convert solar energy into carbohydrates that support growth, development, and yield formation. Although sunlight is freely available, crops differ greatly in their ability to capture and utilize it efficiently. This ability largely depends on canopy architecture, which refers to the spatial arrangement of leaves, stems, branches, and reproductive structures within a crop stand. A well-designed canopy captures more sunlight, distributes it efficiently among leaves, and enhances photosynthesis. In modern agriculture, improving canopy architecture has emerged as an important strategy for increasing productivity, improving resource-use efficiency, and building climate-resilient cropping systems.

What is canopy architecture?

The canopy represents the above-ground portion of a crop community formed by leaves, stems, flowers, and reproductive structures. Canopy architecture describes how these plant components are arranged in space and how they interact with incoming sunlight.

Canopy architecture influences:

- Light interception
- Photosynthetic efficiency
- Air circulation
- Water-use efficiency
- Nutrient utilization
- Pest and disease incidence

An ideal canopy captures maximum sunlight while minimizing self-shading among leaves. Such a canopy allows efficient photosynthesis throughout the crop stand and contributes to higher yields.

Understanding Light Interception

Light interception refers to the proportion of incoming solar radiation captured by the crop canopy. Not all sunlight reaching a field is effectively utilized by plants. A portion may be reflected by leaves, transmitted through canopy gaps, or absorbed by the soil surface.

The greater the amount of sunlight intercepted by leaves, the higher the potential for photosynthesis

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and biomass production. Therefore, efficient canopy design is essential for maximizing crop productivity.

Why Light Interception Matters

Photosynthesis and Biomass Production

Photosynthesis depends directly on the amount of light absorbed by leaves. Crops that intercept more sunlight generally produce greater quantities of carbohydrates, resulting in improved growth and biomass accumulation.

Benefits of efficient light interception include

• Increased photosynthesis

• Greater dry matter production

• Enhanced crop growth

• Better yield formation

Yield Formation

Crop yield depends on the production and allocation of photosynthates. Efficient canopies produce more assimilates that are subsequently transferred to grains, fruits, tubers, and other harvestable plant parts. Consequently, crops with superior canopy structures often achieve higher yield potential.

Components Of Canopy Architecture

Leaf Area Index (LAI)

Leaf Area Index refers to the total leaf area present per unit ground area. It is one of the most important indicators of canopy productivity.

An optimum LAI helps:

• Maximize light interception

• Improve photosynthesis

• Increase biomass production

However, excessive leaf area can result in self-shading and reduced canopy efficiency.

Leaf Angle

Leaf orientation strongly affects light distribution within the canopy.

Horizontal leaves intercept large amounts of sunlight at the canopy surface but may shade lower leaves.

Erect leaves allow sunlight to penetrate deeper into the canopy, improving overall photosynthesis. Modern crop varieties often possess erect leaves that enhance light-use efficiency.

Plant Height

Plant height influences competition for sunlight and canopy structure. Excessively tall plants may increase lodging risk and create uneven light distribution. Moderate plant height often contributes to better canopy performance.

Branching Pattern

The arrangement of branches affects canopy density, light penetration, and airflow. Well-distributed branching improves sunlight utilization and promotes a favorable microclimate within the crop stand.

Table 1. Major canopy traits and their influence on crop productivity

Canopy trait	Effect on crop performance
Leaf area index	Determines total light interception
Leaf angle	Influences light penetration
Plant height	Affects light competition and lodging
Plant density	Controls canopy closure and shading
Branching pattern	Improves light distribution and airflow

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Figure 1. Relationship between canopy architecture and crop productivity.

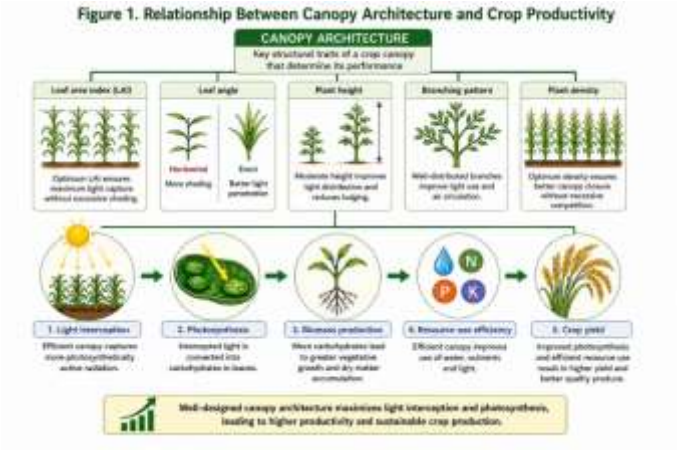

Figure 1. Relationship between canopy architecture and crop productivity. Canopy architecture is determined by structural traits such as leaf area index (LAI), leaf angle, plant height, branching pattern, and plant density. These traits influence the efficiency of light interception within the crop canopy. Improved light interception enhances photosynthesis, leading to greater biomass production, improved resource-use efficiency, and ultimately higher crop yield. Optimized canopy architecture therefore plays a key role in sustainable crop production and efficient utilization of natural resources.

Canopy Architecture And Photosynthesis

Photosynthesis occurs primarily in leaves exposed to sunlight. In dense canopies, upper leaves often receive more light than they can effectively utilize, while lower leaves remain shaded. This uneven distribution reduces overall canopy efficiency.

An efficient canopy distributes sunlight more uniformly throughout the crop stand, ensuring that a greater proportion of leaves contribute to photosynthesis. Such canopies achieve higher productivity and better resource utilization.

Canopy Architecture In Major Crops

Rice

Modern rice varieties have been developed with erect leaves and improved canopy structures. These traits increase light penetration, improve photosynthetic efficiency, and contribute to higher grain yields.

Wheat

In wheat, canopy architecture influences radiation interception, tiller development, and grain filling. Optimized canopy structures enhance yield potential and improve crop performance.

Maize

Modern maize hybrids possess erect leaves and compact plant architecture. These characteristics allow higher planting densities without excessive shading, leading to greater productivity.

Soybean

Canopy structure in soybean influences flowering, pod development, and seed filling. Proper canopy management can significantly improve yield and resource-use efficiency.

Canopy Architecture And Plant Density

Plant population density strongly affects canopy development.

At low plant densities:

• Large canopy gaps occur

• Light interception decreases

• Land resources remain underutilized

At very high plant densities:

• Excessive shading develops

• Air circulation decreases

• Disease incidence may increase

Maintaining optimum plant density is essential for maximizing canopy efficiency and crop productivity.

Canopy Architecture And Water-Use Efficiency

Canopy structure influences transpiration and water use. Well-designed canopies reduce soil evaporation, improve water-use efficiency, and maintain favorable microclimatic conditions. Efficient light interception often results in greater biomass production per unit

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of water consumed, which is particularly important in drought-prone regions.

Canopy Architecture And Nutrient-Use Efficiency

Improved canopy structures enhance nutrient uptake and utilization by increasing photosynthesis and biomass production. Better canopy development can improve nitrogen-use efficiency and increase fertilizer-use efficiency, thereby reducing production costs.

Canopy Architecture And Pest Management

The microclimate within crop canopies significantly influences pest and disease development. Dense canopies often create humid conditions that favor disease outbreaks. Proper canopy management improves air circulation, reduces humidity, and lowers disease pressure.

Examples include:

• Rice blast

• Wheat rust

• Soybean fungal diseases

Canopy Architecture And Climate Change

Climate change poses major challenges to agricultural productivity. Efficient canopy structures can help crops adapt to environmental stresses.

Heat Stress

Optimized canopies improve transpiration cooling and reduce canopy temperature.

Drought Stress

Well-designed canopies reduce water loss while maintaining photosynthetic activity.

Future Climate Scenarios

Future crop varieties may require modified canopy structures to efficiently utilize elevated atmospheric carbon dioxide levels and changing environmental conditions.

Modern Technologies For Canopy Analysis

Recent technological advancements have revolutionized canopy assessment.

Remote Sensing

Drones and satellite imagery help monitor canopy cover, vegetation indices, and crop growth across large areas.

Artificial Intelligence

AI-based image analysis tools can evaluate canopy characteristics and provide real-time management recommendations.

Three-Dimensional Modelling

3D canopy models enable researchers to study light distribution and optimize crop architecture for maximum productivity.

Farmer-Friendly Practices For Better Canopy Management

Farmers can improve canopy efficiency through simple management practices:

• Maintain recommended plant spacing.

• Use optimum seed rate.

• Select varieties with erect leaves.

• Avoid excessive nitrogen application.

• Follow balanced fertilization practices.

• Control weeds during early crop growth.

• Maintain proper irrigation scheduling.

• Monitor crop growth regularly to avoid overcrowding.

Table 2. Benefits of optimum canopy architecture

Benefit	Practical advantage to farmers
Better light interception	Higher photosynthesis and yield

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Improved water-use efficiency	Better drought tolerance
Enhanced nutrient-use efficiency	Better fertilizer response
Improved air circulation	Reduced disease incidence
Uniform crop growth	Easier crop management and harvesting

Future Prospects

Future agricultural productivity will increasingly depend on improving photosynthetic efficiency and resource-use efficiency. Research efforts are focusing on canopy optimization through plant breeding, precision crop management, remote sensing technologies, artificial intelligence, and climate-resilient crop design. The integration of physiology, genetics, and digital agriculture offers tremendous opportunities to enhance crop productivity and sustainability.

Summary

Canopy architecture plays a crucial role in determining how efficiently crops capture and utilize sunlight for growth and yield production. Characteristics such as leaf area, leaf angle, plant height, branching pattern, and plant density influence photosynthesis, water-use efficiency, nutrient uptake, and overall crop performance. Well-designed crop canopies improve light distribution within the plant population, reduce excessive shading, and create a favourable microclimate for growth. Modern crop breeding programmes and precision agriculture technologies increasingly focus on optimizing canopy traits to achieve higher productivity and resource-use efficiency. Proper canopy management can also reduce pest and disease incidence while improving resilience to drought and heat stress. As food demand continues to increase, improving canopy architecture offers a practical and sustainable approach for enhancing crop productivity and ensuring long-term agricultural sustainability.

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Rice stem borer (*Scirpophaga incertulas* Walker) Biology and IPM Approaches for Sustainable Rice Cultivation

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Rice (*Oryza sativa* L.) is one of the most important food crops worldwide, serving as a staple food for more than half of the global population. Among the major constraints to rice production, the yellow stem borer, (*Scirpophaga incertulas* Walker), is considered one of the most destructive insect pests, causing significant yield losses through the formation of dead hearts and white ears. Effective management of this pest is essential for maintaining rice productivity and food security. Sustainable management strategies integrating cultural, mechanical, biological, and need-based chemical control measures offer an environmentally sound approach to suppress stem borer populations. Practices such as synchronized planting, removal of crop residues, conservation of natural enemies, use of entomopathogenic organisms, pheromone-based monitoring, and judicious application of selective insecticides can effectively reduce pest incidence while minimizing environmental risks. Integrated Pest Management (IPM) provides a viable pathway for achieving sustainable rice production and reducing dependence on chemical pesticides.

Introduction

Rice (*Oryza sativa* L.) is the world's most extensively cultivated cereal crop, valued for its exceptionally high caloric yield per unit area compared to other grains (Tagliapietra *et al.,* 2024). Beyond being a staple food, it provides employment and income to millions of rural households. The Yangtze Delta in China-often called the "Big Rice Bowl" is one of the largest rice-producing regions globally. Yet, rice productivity in this region is frequently constrained by biotic stresses, with stem borers ranking among the most destructive insect pests. Several species attack rice stems, including the yellow stem borer (*Scirpophaga incertulas* Walker), dark-headed stem borer (*Chilo polychrysa* Meyrick), gold-fringed stem borer (*Chilo auricilius* Dudgeon), striped stem borer (*Chilo suppressalis* Walker), and pink stem borer (*Sesamia inferens* Walker). Of these, the yellow stem borer is the most dominant, accounting for 60-90% of infestations across rice-growing seasons (Roy *et al.,* 2024). Its widespread distribution and capacity to inflict yield losses ranging from 10% to 60% make it particularly devastating (Murugan *et al.,* 2026). Damage during the vegetative stage manifests as "dead hearts," while reproductive-stage infestations result in "white ear heads." Therefore, the adoption of Integrated Pest Management (IPM) strategies is essential for the sustainable and eco-friendly management of rice stem borers while ensuring higher rice productivity.

Distribution

Scirpophaga incertulas, is widely distributed throughout the major rice growing regions of Asia, including India, China, Bangladesh, Sri Lanka, Pakistan, Nepal, Myanmar, Thailand, Vietnam, Indonesia, and the Philippines. In India, it occurs in almost all rice growing states Bengal, Uttar Pradesh, Chhattisgarh.

Host range

Scirpophaga incertulas Walker, primarily infests rice (*Oryza sativa* L.) and is considered a monophagous pest.

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Life cycle

The life cycle of the yellow stem borer consist of four stage: egg, larvae, pupa, and adult. The insect passes through these stages sequentially during its development. The larval stage comprise five stars and is the most destructive phase of the life cycle. The larvae borne into the rce stem and feed internally, causing significant damage to the crop.

Egg: Adult females lay approximately 150-180 eggs, primarily on the middle to upper abaxial surface of rice leaves or at the tips of leaf blades. The Yellow Stem Borer prefer to lay eggs on the underside of the part of the leaf portion (Sanchez *et al.,* 2023). The egg masses are then covered with buff-colored hairs, providing protection. Depending on the humidity and temperature the incubation period varies from 5 to 9 days.

Larvae: Newly hatched larvae are yellowish-green with a dark brown to black head capsule. As they mature, the larvae become pale yellow to dirty white, fleshy in appearance and retain a distinct dark brown head along with a prominent prothoracic shield. They typically progress through 5 instars before pupation. The larval stage lasts about 21-34 days, with an average duration of 25-29 days, depending on environmental conditions.

Pupa: The pupa is elongated and ranges in color from pale to dark brown, enclosed within a protective white silken cocoon. It measures approximately 12-13 mm in length. Pupation occurs inside the rice stem, usually near the exit hole created by the larva. The pupal stage lasts 5-12 days, with an average duration of 7-10 days, and its length is generally inversely related to temperature shortening under warmer conditions.

Adult: The adult yellow stem bore (*Scirpophaga incertulas* Walker) is a medium sized moth exhibiting sexual dimorphism. Female are pale yellow with a characteristic black spot on each forewing and possess a tuft of yellowish hairs at the tip of the abdomen. The females are bigger than the males. Males are comparatively smaller, straw-colored and lack the distinct black wing spot. Adult longevity ranges from 3-8 days in males and 4-10 days in females, complete 4 to 6 generations each year, depending on environmental conditions.

Nature of damage:

Newly hatched larvae penetrate the internodes of rice stems during the vegetative phase, particularly at the booting or flowering stage. This results in the central leaf whole flailing unfold, turning brown and eventually drying out, while the lower leaves remain green and healthy. During the reproductive stage, larval feeding causes the development of empty or partially filled grains (Bhatt *et al.,* 2018).

Dead heart: During vegetative stage the central leaves shrivel and wither to create a dead tiller which can be easily pulled out, small holes of entry as well as frass can be seen.

White ear: At maturity, panicles become white and chaffy with no grain content, usually with the frass at the base.

Management of *Scirpophaga incertulas*

Cultural control

- Use healthy and pest free seedlings for transplanting.
- Clip seeding leaf tips before transplanting to remove egg masses.
- Avoid excessive application of nitrogenous fertilizes.
- Synchronize planting and harvesting within a locality to break the pest life cycle.
- Remove and destroy stubbles and crop residues after harvest.
- Manipulation of sowing time.
- Use of resistant varieties, IR32, IR77, NERICA 6.

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Mechanical control

- Regularly monitor fields for egg masses and destroy them.
- Collect and remove dead hearts and white ear heads during crop growth.
- Mating disruption as a behavioral control method has been very effective and is a non-chemical way of controlling the yellow stem borer (*Scirpophaga incertulas*) in rice ecosystems.
- Some sex pheromones like Z-11-hexadecenal, Z-13-octadecenal and Z-9 hexadecenal have shown success in controlling stem borers.

Biological control

- It involves the use of natural enemies of an organism such as parasitoids, predators, pathogens, antagonists or competitors' population to suppress a pest population.
- Egg parasitoids such as *Trichogramma japonicum*, *Telenomus spp*., *Tetrastichus schoenobii.*
- These are spiders, dragonflies and earwigs, which feed on both larva and adult stem borers ((Noorhosseini *et al.,* 2010).
- The application of the entomopathogenic nematode *Heterorhabditis indica* to rice cultivars at a rate of 6.7 × 10^4 infective juveniles (IJs) per liter of distilled water, three weeks after planting, was found to be effective against *Maliarpha separatella* infestation in rice fields.
- Some insect pathogens are widely used as biological control agents. Furthermore, important entomopathogenic fungi involved in the management of rice stem borers include *Metarhizium spp*. and *Beauveria spp*.

Chemical control

- Pesticide are recommended when the borer damage is more than 10% for dead heart and white head.
- The conventional agents like Carbofuran 3G @ 25 kg/ha and Cartap hydrochloride 4G @ 25 kg/ha are commonly used due to its systemic effect on the internal feeding larvae.
- Fipronil 5% SC 1000150 ml/ha and Chlorantraniliprole 18.5% SC 150 ml/ha have been found to have great efficacy with comparatively reduced doses, Phosphamidon 40% SL and Quinalphos 25% EC.

Conclusions

Rice stem borers have been considered as the most devastating pests among insect pests that affect rice, which so far requires suitable management strategies to be initiated. Many control measures including biological, cultural and chemical control strategies have been suggested under this review among which fewer of them are practiced in Tanzania. Despite the fact that most of control measures were reported to be effective against rice stem borers, none of them have achieved 100% control as a single management option. Therefore, a need for integration study of different stem borer management options is vital in order to eradicate stem borer problems in the future.

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Solar Energy in Agriculture: Powering the Future of Sustainable Irrigation

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"The future of agriculture depends not only on producing more food, but also on using water and energy more efficiently." In a rapidly changing climate, rising energy costs, declining groundwater resources and growing pressure on agricultural production, the need for sustainable irrigation solutions has become increasingly important. Solar energy offers a promising pathway by providing farmers with a clean, decentralized and renewable source of power for irrigation. By combining solar-powered pumps with efficient irrigation technologies such as drip and sprinkler systems, agriculture can move towards a more energy-efficient, water-saving and climate-resilient future.

Introduction

Agriculture is one of the most important sectors of the Indian economy, but its productivity is closely linked with the availability of reliable and affordable irrigation. For decades, farmers have depended mainly on electric and diesel-powered pumps to lift groundwater and irrigate crops. However, rising energy costs, unreliable electricity supply, dependence on diesel and increasing concerns over groundwater depletion have created a need for cleaner and more economical irrigation technologies.

Solar-powered irrigation systems (SPIS) offer a promising solution to these challenges. Solar pumps use photovoltaic (PV) panels to convert sunlight into electricity, which is then used to operate water pumps. Since sunlight is freely available, particularly in the dry and sunny regions of India, solar energy can substantially reduce recurring expenditure on diesel and electricity while providing farmers with a decentralized source of irrigation energy.

A solar irrigation system generally consists of: Solar photovoltaic (PV) panels , Solar pump and motor, Controller/inverter, Water source, such as a borewell, open well, farm pond or reservoir , Delivery pipes , Irrigation system, such as drip or sprinkler irrigation During daylight hours, solar panels generate electricity. This electricity powers the pump, which lifts water from the available source and delivers it to the field. Solar pumps are available in surface and submersible configurations and may use either AC or DC motors. The appropriate pump capacity depends on factors such as farm size, water requirement, depth of water source, irrigation method and available solar radiation.

Why Solar Energy Matters for Agriculture

1. Reduction in Irrigation Cost

One of the most important advantages of solar irrigation is the reduction in recurring energy expenditure. Unlike diesel pumps, solar pumps do not require regular purchases of diesel, while solar pumping can also reduce dependence on purchased electricity. The economic feasibility of solar irrigation has been demonstrated in field-based research. using field survey data from three districts of Andhra Pradesh, found that although the initial capital cost of solar pumps was substantially higher than diesel pumps, their operation and maintenance costs were significantly lower, making solar

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irrigation economically viable over the system's life cycle.

2. Reliable Access to Irrigation

Electricity supply to agriculture may be affected by power cuts, voltage fluctuations and supply schedules. A solar pump can provide farmers with greater control over irrigation during daylight hours, reducing dependence on the timing of grid electricity. This is particularly valuable in areas where electricity supply is inadequate or where diesel is the main alternative.

3. Lower Dependence on Diesel

Diesel-powered irrigation involves continuous expenditure on fuel and maintenance. Solar irrigation eliminates direct diesel consumption for pumping and therefore contributes to the de-dieselisation of agriculture. The Government of India's PM-KUSUM programme specifically promotes standalone solar pumps as an alternative to diesel pumps in off-grid agricultural areas.

4. Environmental Benefits

Solar irrigation produces electricity without direct combustion of fossil fuels at the point of use. Replacing diesel pumps with solar pumps can therefore reduce greenhouse-gas emissions and local air pollution. As of July 2025, the Government estimated that solar pumps and solar plants installed under PM-KUSUM had contributed to mitigation of approximately 6.6 million tonnes of CO_2 emissions.

PM-KUSUM: A Major Push for Solar Agriculture

The Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) is one of India's major programmes promoting renewable energy in agriculture.

The scheme has three broad components:

Component	Major Focus
A	Decentralized grid-connected renewable energy plants
B	Standalone solar agriculture pumps
C	Solarisation of grid-connected agricultural pumps, including feeder-level solarisation

The scheme aims not only to provide clean energy for irrigation but also to reduce farmers' irrigation costs, reduce diesel dependence and improve farmers' income opportunities.

According to the Ministry of New and Renewable Energy/PIB, up to 31 December 2025, PM-KUSUM had benefited 21,77,369 farmers. Under Component B, 9,75,227 standalone solar pumps had been installed, while 12,01,552 pumps had been solarised under Component C.

PM-KUSUM Progress in India

Indicator	Achievement up to 31 Dec. 2025
Farmers benefited	21.77 lakh
Standalone pumps under Component B	9.75 lakh
Pumps under Component C	12.02 lakh
Component A installed capacity	720.91 MW
Solar capacity under Component B	4,398.57 MW
Solar capacity under Component C	5,829.98 MW

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Source: Ministry of New and Renewable Energy/Press Information Bureau, Government of India.

Solar Pump as an Economic Investment

The major limitation of solar irrigation is its high initial investment. A solar pump requires expenditure on PV modules, pump, mounting structure, controller/inverter, installation and related infrastructure. However, its economics should not be evaluated only on the basis of initial purchase price. A proper comparison should consider the life-cycle cost, including:

Initial investment + operation and maintenance cost + fuel/electricity expenditure + replacement cost – residual value.

Solar pumps have very low recurring energy costs because sunlight is the primary energy source. Consequently, the higher initial investment can potentially be recovered over time through savings in diesel or electricity expenditure. Research from Andhra Pradesh reported that the capital cost of an SPV pump per horsepower was substantially higher than that of a diesel pump, but its operation and maintenance costs were significantly lower.

Solar Irrigation and Water Conservation: A Necessary Partnership

Solar pumps solve an energy problem, but they do not automatically solve a water-management problem. Because sunlight is free, the marginal cost of pumping water can become very low. If farmers respond by pumping excessive groundwater, solar irrigation may unintentionally contribute to groundwater depletion.

Therefore, solar pumping should be promoted together with: Drip irrigation, Sprinkler irrigation, Farm ponds , Mulching , Water harvesting, Crop diversification toward less water-intensive crops , Soil-moisture-based irrigation scheduling , Efficient pump sizing

The sustainable implementation of solar irrigation therefore requires an integrated Water–Energy–Food approach rather than simply replacing diesel or electric pumps with solar pumps.

Solar Energy + Micro-Irrigation: A Powerful Combination

The greatest benefits can be achieved when solar pumping is combined with efficient irrigation technologies.

Solar Pump → Efficient Water Lifting → Drip/Sprinkler → Less Water Loss → Lower Irrigation Cost → Better Resource Use → Higher Farm Sustainability

For example, drip irrigation delivers water directly to the root zone, while solar energy reduces the recurring energy cost of pumping. Together, these technologies can improve the efficiency of both water and energy.

Solar Irrigation and Farmer Income

Solar energy can contribute to farm income in several ways:

1. Lower expenditure on diesel and electricity
2. Greater reliability of irrigation
3. Possibility of increasing cropping intensity
4. Opportunity to cultivate higher-value crops
5. Potential income from surplus electricity in eligible grid-connected systems
6. Reduced exposure to fluctuations in fossil-fuel prices

Recent research based on a survey of 814 farmers across Rajasthan, Uttar Pradesh, Odisha and Tamil Nadu found that solar pump adoption reduced diesel consumption by 36–91% across districts, although the effects varied by location and groundwater conditions. The study highlights that the economic benefits of solar irrigation depend not only on installation but also on how effectively farmers use the pumps.

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Relevance for Rajasthan

Rajasthan has particularly strong potential for solar-powered agriculture because of its high solar radiation, large agricultural area and significant dependence on groundwater irrigation.

For farmers in water-stressed regions, however, solar pumping should be linked with efficient water management. The objective should not simply be **"more pumping"**, but rather **"more crop per unit of water and energy."**

This makes the combination of solar irrigation + drip/sprinkler irrigation + scientific crop planning particularly important for sustainable agriculture in Rajasthan.

Challenges in Adoption

Despite its advantages, several challenges need attention:

High Initial Cost

The initial cost of a solar pump is considerably higher than that of conventional pumps, although subsidies and financing can reduce the farmer's burden.

Groundwater Depletion

Low-cost solar pumping may encourage excessive groundwater extraction if appropriate safeguards are absent.

Dependence on Solar Radiation

Pump performance varies with sunlight availability, and water pumping is generally strongest during sunny hours.

Technical Maintenance

Farmers need access to reliable after-sales service, spare parts and trained technicians.

Land Requirement

Solar panels require suitable, shadow-free space.

Awareness and Technical Knowledge

Farmers need guidance regarding pump sizing, irrigation scheduling, maintenance and efficient water use.

The Way Forward

The future of solar energy in agriculture should move beyond simply installing more solar pumps. The focus should be on developing smart, water-efficient and economically sustainable solar irrigation systems.

Future interventions should emphasize: Solar pumps integrated with drip and sprinkler irrigation, Smart controllers and automated irrigation , Water-level monitoring , Solar pump sizing based on actual crop water requirements , Community solar irrigation systems, Farmer Producer Organizations and Water User Associations , Affordable credit and suitable subsidy mechanisms, Training and after-sales services, Solarisation of agricultural feeders , Agrivoltaics and dual-use of agricultural land.

The PM-KUSUM framework also allows grid-connected renewable energy plants on suitable barren/fallow land and provides opportunities for farmers to become both "Annadata" and "Urjadata."

Conclusion

Solar energy has the potential to transform agricultural irrigation from a fossil-fuel- and grid-dependent activity into a cleaner, decentralized and potentially more economical energy system. Its benefits extend beyond saving diesel or electricity: reliable irrigation can support crop diversification, improve resource-use efficiency and create new opportunities for farm income.

However, solar irrigation should not be treated as a stand-alone solution. Its long-term success depends on integrating renewable energy with efficient water management, appropriate crop planning and responsible groundwater use.

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The future vision should therefore be:

"More Crop, Less Water, Cleaner Energy and Higher Farm Income."

With appropriate policies, technological innovation and farmer participation, solar energy can become a major pillar of sustainable and climate-resilient agriculture in India, particularly in solar-rich and water-stressed regions such as Rajasthan.

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White Biotechnology: Sustainable Innovations For The Future

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Biotechnology is the application of biological organisms, systems, or processes to develop products and technologies that improve human life and the environment. Biotechnology is commonly classified into different categories based on its area of application:

- Red biotechnology – medical and pharmaceutical applications.
- Green biotechnology – agricultural applications.
- White biotechnology – industrial applications.
- Blue biotechnology – marine and aquatic applications.

Introduction

Among these, white biotechnology has emerged as one of the most promising fields for achieving sustainable industrial growth. White biotechnology, also known as industrial biotechnology, involves the application of biological systems, microorganisms, enzymes, and biocatalysts in industrial processes to produce valuable products and services. It represents a sustainable alternative to conventional chemical manufacturing by utilizing renewable resources, reducing energy consumption, minimizing waste generation, and lowering greenhouse gas emissions. White biotechnology has transformed numerous sectors, including pharmaceuticals, food and beverages, agriculture, textiles, biofuels, paper, and chemical industries. This article explores the principles, applications, advantages, challenges, and future prospects of white biotechnology, highlighting its significant contribution to sustainable industrial development and the circular bioeconomy. It utilizes microorganisms such as bacteria, fungi, yeasts, algae, and enzymes to manufacture industrial products efficiently and environmentally responsibly. Traditional industrial processes often depend on petroleum-based raw materials, high temperatures, toxic chemicals, and energy-intensive operations. White biotechnology offers an alternative approach by employing biological catalysts that function under mild conditions, thereby reducing environmental impact.

As concerns regarding climate change, resource depletion, and environmental pollution continue to grow, white biotechnology is increasingly recognized as a key technology for achieving sustainable development and supporting the global transition toward a bio-based economy.

Historical Development of White Biotechnology

The foundations of white biotechnology can be traced back thousands of years to ancient fermentation practices used in the production of bread, beer, wine, and cheese. Although these processes were not initially understood scientifically, they demonstrated the industrial potential of microorganisms.

Significant milestones include:

- Discovery of microorganisms by Antonie van Leeuwenhoek in the 17th century.
- Development of fermentation technology by Louis Pasteur in the 19th century.
- Industrial production of antibiotics during the 20th century.
- Advancement of genetic engineering and recombinant DNA technology in the 1970s.

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- Emergence of modern industrial biotechnology in the late 20th and early 21st centuries.

Today, advancements in molecular biology, genomics, synthetic biology, and metabolic engineering have expanded the capabilities of white biotechnology, enabling the production of a wide range of bio-based chemicals and materials.

Principles of White Biotechnology

White biotechnology relies on biological systems to perform industrial processes more efficiently than traditional chemical methods.

Use of Microorganisms

Microorganisms such as bacteria, fungi, and yeast are employed as biological factories to produce: Organic acids, Amino acids, Vitamins, Enzymes, Biofuels & Bioplastics. These organisms can be genetically modified to enhance productivity and process efficiency.

Types of white biotechnology include :

Enzyme Technology

Enzymes are highly specific biological catalysts that accelerate chemical reactions without being consumed. Important industrial enzymes include: Amylases, Proteases, Lipases Cellulases and Xylanases. Enzymes operate under mild conditions and generate fewer unwanted by-products compared to chemical catalysts.

Fermentation Technology

Fermentation is a biological process in which microorganisms convert substrates into useful products. Common fermentation products include: Ethanol,Lactic acid,Citric acid ,Antibiotics and Industrial enzymes

Metabolic Engineering

Metabolic engineering involves modifying cellular pathways to increase production of desired compounds and reduce formation of unwanted products.

Synthetic Biology

Synthetic biology combines engineering principles with biology to design and construct new biological systems capable of producing innovative industrial products.

Major Applications of White Biotechnology

White biotechnology has widespread applications across numerous industries.

Biofuel Production

One of the most important applications is the production of renewable biofuels.

Bioethanol

Bioethanol is produced through fermentation of sugars derived from: Sugarcane,Corn, Wheat & Lignocellulosic biomass. It serves as an alternative to gasoline and reduces greenhouse gas emissions.

Biodiesel

Biodiesel is produced from vegetable oils, animal fats, and microbial lipids through biological and chemical processes.

Biogas

Organic wastes are converted into methane-rich biogas through anaerobic digestion, providing a renewable energy source.

Enzyme Industry

Industrial enzymes are extensively used in manufacturing processes.

Detergent Industry

Proteases, lipases, and amylases improve stain removal and washing efficiency.

Food Industry

Enzymes assist in:Bread making,Cheese production,Fruit juice clarification &Brewing

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Textile Industry

Enzymes replace harsh chemicals in: Fabric finishing, Bio-polishing and Denim washing

Bioplastics Production

Conventional plastics contribute significantly to environmental pollution. White biotechnology enables production of biodegradable plastics such as:Polyhydroxyalkanoates (PHA) and Polylactic acid (PLA).These materials are produced from renewable biological resources and decompose naturally under suitable conditions.

Pharmaceutical Manufacturing

Industrial biotechnology contributes to pharmaceutical production through microbial fermentation and enzyme-based synthesis. Examples include :Antibiotics, Vaccines, Insulin. Vitamins, Therapeutic proteins and Biotechnological processes improve product quality and reduce production costs.

Food and Beverage Industry

White biotechnology enhances food quality, safety, and nutritional value. Applications include:Fermented foods, Probiotics,Food additives,Flavor compounds and Nutritional supplements. Examples:Yogurt,Cheese, Vinegar, Soy sauce

Paper and Pulp Industry

Traditional paper production consumes large quantities of chemicals and energy.

Biotechnological solutions utilize enzymes for: Pulp bleaching, Fiber modification and Deinking recycled paper

Benefits include reduced chemical usage and lower environmental pollution.

Waste Management and Environmental Protection

Microorganisms play a crucial role in waste treatment and pollution control.

Applications include: Bioremediation,Wastewater treatment, Composting and Industrial waste degradation.These processes help restore contaminated environments and support sustainable resource management.

Advantages of White Biotechnology

White biotechnology offers numerous environmental, economic, and social benefits.

Environmental Benefits

- Reduced greenhouse gas emissions
- Lower energy consumption
- Reduced toxic waste generation
- Increased use of renewable resources
- Enhanced biodegradability of products

Economic Benefits

- Improved production efficiency
- Reduced operational costs
- Increased product yield
- Creation of new industrial markets

Resource Conservation Biological processes often require fewer raw materials and allow utilization of agricultural residues and industrial wastes.

Sustainable Development

White biotechnology supports the United Nations Sustainable Development Goals (SDGs) by promoting cleaner production methods and resource efficiency.

Role of Genetic Engineering in White Biotechnology

Genetic engineering has revolutionized industrial biotechnology.

Scientists can modify microorganisms to: Produce higher quantities of enzymes, Generate biofuels more efficiently, Synthesize novel chemicals and Utilize alternative feedstocks

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Challenges and Limitations

- **High Initial Investment** Establishing biotechnological production facilities requires significant capital investment.
- **Feedstock Availability** Reliable and sustainable supply of biomass remains a major concern.
- **Process Optimization** Biological systems can be sensitive to environmental conditions, requiring careful process control.
- **Regulatory Issues** Strict regulations govern genetically modified organisms (GMOs) and biotechnology products.
- **Public Acceptance** Public concerns regarding genetic engineering and biotechnology may limit adoption in some regions.

Future Prospects

The future of white biotechnology is highly promising. Growing concerns about climate change, environmental sustainability, and resource scarcity are driving investment and innovation in this field. Future developments may include: Advanced biofuels with improved efficiency, Sustainable aviation fuels, Carbon-neutral chemical manufacturing, Biodegradable packaging materials, Smart biorefineries and Large-scale waste-to-value technologies The integration of biotechnology with artificial intelligence, nanotechnology, and systems biology will further enhance industrial productivity and sustainability. As governments and industries increasingly adopt green technologies, white biotechnology is expected to become a cornerstone of the global bioeconomy.

Conclusion

White biotechnology represents a transformative approach to industrial production by utilizing biological systems for sustainable manufacturing. Through the application of microorganisms, enzymes, fermentation technology, genetic engineering, and synthetic biology, it provides environmentally friendly alternatives to conventional industrial processes. Its applications span multiple sectors, including energy, chemicals, pharmaceuticals, food, textiles, paper, and environmental management. White biotechnology contributes significantly to reducing pollution, conserving resources, lowering energy consumption, and promoting sustainable economic growth.

Although challenges such as high investment costs, regulatory concerns, and feedstock limitations remain, ongoing scientific advancements continue to expand its potential. With increasing global emphasis on sustainability and circular economy principles, white biotechnology is poised to play a vital role in shaping the future of industrial development and environmental stewardship.

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Colchicine in Crop Improvement: Mechanism, Application and Alternatives

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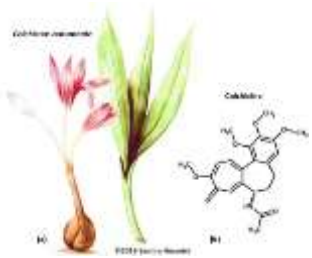
Colchicine is a naturally occurring chemical primarily obtained from the bulbs of *Colchicum autumnale*. It is widely used in plant breeding for the induction of polyploidy through chromosome doubling. Polyploidization can result in beneficial changes in plants, including increased organ size, vigour, and, in some cases, improved yield. Consequently, it has been extensively used for crop improvement in both horticultural and agricultural crops. One of its most notable applications is in seedless watermelon breeding, where colchicine is used to develop tetraploid (4x) plants that are subsequently crossed with diploid (2x) plants to produce triploid (3x) seedless watermelons. Colchicine has also been utilized in crops such as rice and sorghum for chromosome manipulation and the development of improved breeding materials. However, besides colchicine, several other antimitotic chemicals, including oryzalin, amiprophos-methyl (APM), caffeine, and trifluralin, are also used for the induction of polyploidy. Therefore, these chromosome-doubling agents play an important role in creating novel genetic variation and expanding opportunities for crop improvement.

What is Colchicine?

Colchicine is a secondary metabolite that belongs to the category of alkaloids. It is naturally obtained from the plant *Colchicum autumnale*, which belongs to the family Colchicaceae. It is highly toxic and is extracted from bulbs (0.1-0.5%) and seeds (0.2-0.8%) and is readily soluble in cold water, chloroform or alcohol but it has low solubility in hot water (Manzoor et al 2019). Dried plant parts contain almost the same amount of colchicine as fresh parts. However, dried flowers and seeds contain about 15 times more colchicine than leaves.

In addition to colchicine, several related alkaloids are also present in the plant, including Colchicerine, Colchamine, Colchicoside, Demethyl-3-colchicine, Cornigerine, 2-demethylcolchicoline. (Akram et al 2012).



Chemical Formula : $C_{22}H_{25}NO_6$

The extraction of colchicine generally involves several steps. First, the seeds or corms are collected, cleaned to remove adhering foreign matter and dried to reduce moisture content. The dried material is then finely powdered. This is followed by solvent extraction using methods such as maceration, Soxhlet extraction or reflux with solvents like ethanol, methanol, chloroform or acetone. The obtained extract is then filtered to remove solid residues and concentrated by evaporating the solvent. Finally, the crude extract is purified using chemical methods to obtain colchicine in a usable form (Abidin et al., 2015).

Mode of Action of colchicine:

Polyploidy refers to the condition in which a plant has more than two sets of chromosomes. It is important in plant breeding because polyploid plants often show desirable traits such as increased size, higher yield, better vigor and improved stress tolerance. To develop such plants, chromosome doubling is required and this is where colchicine plays an important role. Colchicine is widely used to

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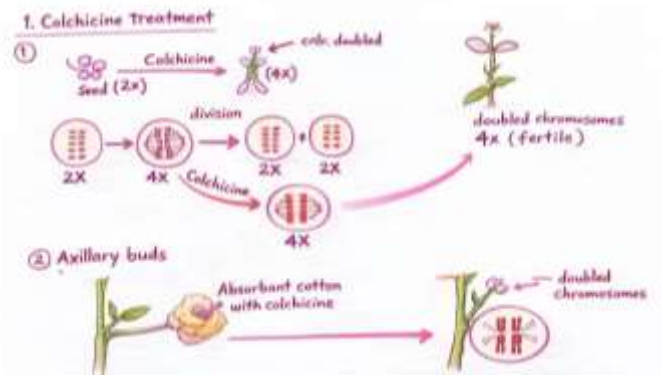
artificially induce polyploidy in plants. Colchicine induces chromosome doubling by binding to tubulin, a structural protein involved in the formation of microtubules. This disrupts spindle fiber formation during cell division (Singh et al., 2025).

Since microtubules are essential for chromosome separation, colchicine prevents proper segregation of chromosomes. As a result, chromosomes fail to separate and remain in the same cell, leading to doubling of chromosome number and formation of polyploid cells. Because of this property, colchicine is widely used to induce polyploidy in plants. It acts as a mitotic poison and can also produce mutagenic effects. Plants developed through such mutations are known as colchi-mutants (Manzoor et al., 2019).



(Image generated using A.I)

Methods of Application:

Table: Methods of Colchicine Application

Part	Concentration & Duration	Procedure	Example	Advantages	Limitations
Seed	0.001-1% (commonly 0.2%), 1-10 days	Seeds are soaked in colchicine solution in shallow containers for proper aeration	*Sesamum indicum*	Simple and easy	Uneven absorption, chances of chimeras
Shoot Apex	0.1-1%, applied for several days	Applied using brush, dropper or cotton swab to apical meristem; repeated daily	*Cosmos sulphureus, Chrysanthemum*	More effective, targets meristematic cells	Requires care; may damage growing tip
Woody Plant	~1%	Applied to buds with addition of wetting agent for better penetration	-	Useful for woody species	Limited penetration; slower response
Corm/ Bulb	0.1-0.3%, ~24 hrs	Soaked in solution before planting; DMSO may be	*Gladiolus grandiflorus*	Effective for vegetative	Risk of toxicity if overtreated

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		added for better absorption		propagation crops	

(Ninama et al 2020; Kishor kumar and Uma Rani, 2013)

Since the effect of colchicine depends on its concentration and duration, its mode of action is important to understand. Colchicine induces polyploidy in two stages: first, chromosome number increases without nuclear abnormalities; second, prolonged or higher exposure leads to abnormal nuclei and irregular chromosome numbers. Thus, the response varies with the level and duration of treatment (Eigsti, 1938).

Alternatives to colchicine used for inducing polyploidy in plants:

Alternatives to colchicine have gained importance due to lower toxicity and higher efficiency. **Oryzalin** inhibits spindle formation at nearly 1000 times lower concentration than colchicine and is preferred because it is safer, cheaper and causes fewer chromosomal abnormalities; it also shows no affinity to animal tubulin and has higher specificity for plant tubulin, making it effective at lower doses. For example, chromosome doubling was successfully induced in vitro in a diploid hybrid of *Rosa rugosa* (Allum et al., 2007). Similarly, **trifluralin** disrupts spindle microtubules like colchicine but has a higher affinity for plant tubulin and produces results within about 30 minutes compared to several hours required for colchicine treatment (Ebrahimzadeh et al., 2018). Among other antimicrotubule herbicides, **amiprophos-methyl (APM)** has shown considerable potential for in vitro chromosome doubling at concentrations 100-1000 times lower than colchicine, with effectiveness comparable or superior in beet ovule culture (Hansen et al., 2000). Additionally, **caffeine** can induce binucleate and multinucleate cells by inhibiting cytokinesis, where cell plate formation is initiated but not completed (Broughton et al., 2020).

Advantages and Disadvantages of colchicine

Advantages	**Disadvantages**
Highly effective for chromosome doubling	Can be toxic to humans
Widely used and well-studied	Requires careful handling
Applicable to many crops	Can cause chromosomal abnormalities
Easy application (seed, seedling, tissue)	High concentration can cause plant death
Improves traits (yield, vigor, size)	Often produces chimeras
Helps in hybrid fertility restoration	Requires longer exposure time
Predictable results in many cases	Less specific compared to newer chemicals

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Biosensors for Rapid Plant Pathogen Detection

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Plant diseases are a major threat to agricultural productivity and food security, making rapid and accurate pathogen detection essential for timely disease management. Conventional diagnostic methods often require laboratory facilities, trained personnel, and considerable time, creating challenges for field-level diagnosis. Biosensor technology offers a promising alternative by enabling rapid, sensitive, and potentially portable detection of plant pathogens. Recent advances in nanomaterials, CRISPR-based detection, microfluidics, and smartphone-integrated systems are improving the sensitivity, specificity, speed, and portability of these diagnostic tools. Biosensors can potentially detect pathogens at an early stage, even before visible disease symptoms appear, allowing farmers to make timely and informed management decisions. However, challenges related to cost, stability, field validation, standardization, and large-scale commercialization still need to be addressed. With continued technological innovation and integration with digital and precision agriculture, biosensors have the potential to transform plant disease diagnosis from a laboratory-based process into a rapid, affordable, and farmer-friendly field technology, contributing to more sustainable and efficient crop protection.

Plant diseases are a major threat to global food production, affecting crop yield, quality, farmer livelihoods, and food security. Plant pathogens such as fungi, bacteria, viruses, and nematodes can spread rapidly through agricultural fields, and significant yield losses may occur before disease symptoms become clearly visible. Globally, plant pathogens and pests are estimated to cause losses of up to 40 per cent of crop production annually, creating enormous economic and environmental consequences. Early and accurate detection is therefore essential for effective disease management. Conventional diagnosis often relies on visual inspection, microbial culturing, microscopy, or laboratory-based molecular techniques. While these methods can provide reliable identification, they may require skilled personnel, specialised equipment, and considerable time. Moreover, visual symptoms alone are often insufficient to distinguish between diseases with similar appearances. Rapid detection can help farmers respond before a disease becomes widespread and can support the targeted use of fungicides and other control measures. This is particularly important as excessive and repeated pesticide use can contribute to pathogen resistance and environmental problems. The need for diagnostic tools that are rapid, sensitive, accurate, portable, and suitable for field use has therefore become increasingly important. One promising technology addressing this need is the biosensor. By combining biological recognition with a physical or electronic sensing system, biosensors can detect specific pathogens or pathogen-associated molecules and convert their presence into a measurable signal. These emerging tools have the potential to bring plant disease diagnosis from the laboratory directly to the field, enabling faster decisions and more sustainable disease management.

The importance of early detection

Plant diseases can cause serious losses in crop yield and quality, and the problem is becoming more

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challenging as agricultural production intensifies. The earlier a disease is detected, the easier it is to control. Traditional disease diagnosis methods such as visual inspection, microbial culturing, PCR and ELISA have played an important role in identifying plant pathogens. However, many of these methods depend on laboratories, specialised equipment, trained personnel and sample processing. Early detection is especially important for managing diseases in fields, greenhouses, nurseries and during the movement of planting materials. Rapid diagnosis can help prevent the spread of serious or quarantine pathogens and support timely disease management. Scientists have developed several approaches for detecting plant diseases. DNA- and RNA-based methods can identify pathogens with high accuracy, while immunoassays such as ELISA and lateral flow devices can detect pathogen proteins and are useful for on-site testing. Plants can also produce specific volatile organic compounds (VOCs) when attacked by pathogens, providing another possible signal for disease detection. Despite their advantages, conventional molecular and laboratory methods may be difficult to use directly in the field. This has created a need for diagnostic tools that are rapid, sensitive, portable, affordable, and easy to operate. Biosensors are emerging as one such solution. They can recognise specific pathogen molecules and convert that recognition into a measurable signal, offering the possibility of detecting plant diseases quickly and closer to where the crops are growing. Instead of waiting for a disease to become clearly visible and widespread, biosensor-based technologies could help identify the problem sooner—allowing faster decisions, reducing unnecessary chemical applications, and protecting more of the crop.

Understanding Biosensors

A biosensor is a small device that uses a biological component to detect a specific substance and converts that detection into a signal that we can measure (Nguyen *et al.,* 2024). In plant disease detection, this means the device can recognise a particular pathogen or a molecule produced by it and provide a quick indication of whether the disease is present. A biosensor contains two main parts. The first is a biological recognition element that can specifically recognise the target pathogen. This may be an antibody, a short piece of DNA or RNA, an enzyme or newer recognition systems based on technologies such as CRISPR. Like a lock and key, the recognition element is designed to interact with a particular target. The second part is called a transducer. It converts this biological interaction into a measurable signal. Depending on the type of biosensor, the signal may appear as a change in electrical current, light, or colour. This makes it possible to detect a pathogen without relying entirely on traditional laboratory procedures. The idea of biosensors is not new. The development of the Clark oxygen electrode by Leland C. Clark laid the foundation for modern biosensor technology. Later, biosensor-based glucose monitoring became one of the best-known practical applications, demonstrating how biological recognition and sensing technology could be combined to provide rapid measurements. Today, biosensors are being explored for many applications, including environmental monitoring, food safety, medical diagnosis, pesticide detection and plant pathogen detection. Their ability to provide rapid, sensitive, portable and relatively simple testing makes them particularly promising for agriculture. For plant disease management, the biggest advantage is simple: the laboratory can potentially come to the plant, rather than the plant sample having to go to the laboratory. This could help farmers detect diseases earlier, respond faster and use disease-control measures more precisely.

Types of biosensors

Biosensors used for plant pathogen detection can be broadly classified according to the type of signal generated, with electrochemical, optical, and colorimetric biosensors being among the most widely investigated approaches. Electrochemical biosensors

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consist of a biological recognition element, such as an antibody or nucleic acid probe, coupled with an electrochemical transducer that converts the interaction between the target pathogen and the recognition element into a measurable electrical signal (Ronkainen *et al.,* 2010). These sensors offer high sensitivity and can provide quantitative detection of pathogens in plant tissues, seeds, water, greenhouse environments, and field conditions (Fang and Ramasamy, 2015). Optical biosensors, in contrast, detect pathogen–recognition interactions through changes in light properties such as intensity, wavelength, phase, or frequency, and include fluorescence-based and surface plasmon resonance (SPR)-based systems (Ray *et al.,* 2017). Fluorescence-based biosensors can offer highly sensitive detection and are particularly useful when pathogens are present at very low concentrations, although they generally require a suitable light source or detection device. SPR biosensors detect changes at the sensor surface following the binding of pathogen molecules to the recognition layer and can provide rapid and sensitive measurements, but their instrumentation is relatively more complex. Colorimetric biosensors are among the simplest and most practical systems for field applications because pathogen detection produces a visible colour change that can often be observed directly without specialised equipment. Lateral flow assays are a widely used example of this approach, in which the sample moves through a paper-based strip containing specific biological reagents and produces a visible test line when the target pathogen is present (Khater *et al.,* 2017). Colloidal gold is commonly used as a visible label because of its strong colour and ease of detection without additional instruments (Koczula and Gallotta, 2016). Thus, while electrochemical biosensors provide sensitive and quantitative measurements, optical systems offer highly sensitive detection through light-based signals, and colorimetric biosensors provide simplicity, portability, rapid results, and ease of use. The selection of a particular biosensor therefore depends on the required sensitivity, speed, cost, portability, and practical conditions of pathogen detection, with the ultimate goal of providing reliable and timely diagnosis directly at the site of crop production.

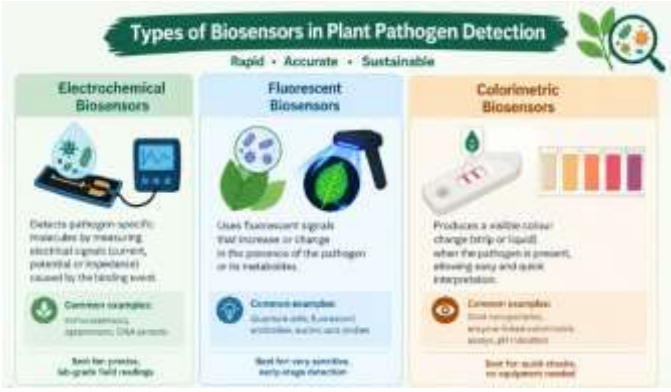

Figure 1: Types of biosensors

Nanotechnology-Enabled Biosensors

One of the important advances in biosensor technology has been the integration of nanomaterials, which are extremely small materials with unique physical, chemical, electrical, and optical properties (Narware *et al.,* 2025). Their incorporation into biosensors can greatly improve sensitivity, detection speed, and overall performance. Nanomaterials provide a large surface area for attaching biological recognition elements such as DNA, antibodies and enzymes, allowing more target molecules to interact with the sensor. Their excellent electrical conductivity and special optical properties can further enhance signal generation and enable the detection of very small quantities of plant pathogens. A variety of nanomaterials have been explored for biosensor development, including metal and metal oxide nanoparticles, quantum dots, carbon-based materials such as carbon nanotubes and graphene, and polymeric nanomaterials. The practical potential of these technologies is already being demonstrated in plant disease detection. For example, nanomaterial-based paper-strip biosensors have been developed for detecting Banana bunchy top virus, with gold nanoparticles linked to specific DNA sequences providing highly sensitive and selective detection (Narware *et al.,* 2025). Such developments demonstrate how nanomaterials can strengthen

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biosensors and push plant pathogen detection towards faster, more sensitive, and potentially field-ready diagnosis.

Challenges and Future Prospects

Despite the remarkable progress in biosensor-based plant pathogen detection, several challenges still need to be addressed before these technologies can become routine diagnostic tools in agriculture. One of the major limitations is cost. Although advances in nanomaterials, microfluidics, CRISPR-based recognition systems, and portable electronics are making biosensors increasingly affordable, many sophisticated platforms remain largely confined to research laboratories and are yet to reach widespread commercial use, particularly among smallholder farmers. The cost of sensor fabrication, biological recognition elements, specialized components, and supporting equipment can still limit their adoption. Another important challenge is stability and shelf life, as biosensors often rely on biological components such as antibodies, enzymes, nucleic acids, or other recognition molecules that may lose their activity under unsuitable temperature and storage conditions. Future research should therefore focus on validating biosensors across diverse crops, geographical regions, pathogen strains, and environmental conditions while establishing common standards for sensitivity, specificity, detection limits, reproducibility, and practical usability. Despite these challenges, the future of biosensor-based plant disease diagnostics is highly promising.

Conclusion

Biosensor-based plant pathogen detection represents a promising shift towards faster, simpler, and more precise plant disease diagnosis. By combining biological recognition with advances in nanotechnology, CRISPR, microfluidics, and digital technologies, these tools have the potential to bring laboratory-level diagnostics directly to the field. Although challenges related to cost, stability, validation, and large-scale adoption remain, continued innovation is steadily overcoming these barriers. In the future, affordable and portable biosensors could help farmers detect diseases at an early stage, make timely management decisions, reduce unnecessary pesticide use, and minimize crop losses. Thus, biosensors are not merely diagnostic devices they could become an important foundation for smarter, sustainable, and precision-driven plant health management.

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When Stress Becomes Strength: How Plants Produce Powerful Medicinal Compounds

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Plants are constantly exposed to environmental and biological stresses, including drought, salinity, heat, ultraviolet radiation, insect attack and pathogen infection. Unlike animals, they cannot escape these adverse conditions and instead activate sophisticated defence mechanisms to survive. One of the most remarkable responses is the production of secondary metabolites such as alkaloids, flavonoids, phenolic compounds, terpenoids and essential oils. Although these compounds primarily function as protective molecules in plants, they also possess significant antioxidant, antimicrobial, anti-inflammatory and therapeutic properties that make medicinal and aromatic plants valuable to human health. Research has shown that moderate levels of stress can stimulate the accumulation of these bioactive compounds, whereas excessive stress often reduces plant growth and productivity. Understanding these stress-induced metabolic responses provides valuable opportunities for improving the quality of medicinal crops through scientific cultivation practices and controlled elicitation. This article explores how different environmental and biological stresses influence the biosynthesis of medicinal compounds and highlights their importance for sustainable agriculture, herbal medicine, pharmaceuticals and the growing medicinal and aromatic plant industry.

Introduction

Plants, like all living organisms, face numerous challenges throughout their life cycle. Unlike humans and animals, however, they cannot move away from harsh environmental conditions or escape attacks from insects and pathogens. Instead, they survive by activating sophisticated defence mechanisms that help them adapt to stressful conditions. One of the most remarkable responses is the production of specialized chemical compounds known as secondary metabolites. These compounds are not directly involved in normal growth and development but play a crucial role in protecting plants from environmental stress and biological threats.

Interestingly, many of these defensive compounds are the very substances that make medicinal and aromatic plants valuable to humans. Alkaloids, flavonoids, phenolic compounds, terpenoids and essential oils, synthesized by plants as part of their survival strategy, possess antioxidant, antimicrobial, anti-inflammatory and therapeutic properties that have been widely utilized in traditional and modern medicine. Thus, what serves as a natural defence system for plants becomes an important source of pharmaceuticals, nutraceuticals, cosmetics and herbal products for people.

Scientific studies have demonstrated that environmental stresses such as drought, salinity, extreme temperatures, ultraviolet radiation and nutrient deficiency can alter the biosynthesis and accumulation of these bioactive compounds. In many medicinal and aromatic plants, moderate levels of stress stimulate the production of valuable phytochemicals, whereas excessive or prolonged stress may adversely affect plant growth and yield. This delicate balance between survival and productivity highlights the remarkable adaptability of plants and offers new opportunities for improving the

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quality of medicinal crops through scientific cultivation practices.

Understanding how plants transform environmental challenges into biochemical strength not only reveals the fascinating science behind medicinal plants but also provides valuable insights for farmers, researchers and the herbal industry. This article explores how different forms of stress influence the production of medicinal compounds and why these natural survival mechanisms hold immense significance for agriculture, healthcare and sustainable production.

Nature's Toughest Challenge: What Does Stress mean to a Plant?

Imagine standing under the scorching sun without water for days, surrounded by insects feeding on your body while being unable to move even a single step. This is the reality for plants every day. Unlike humans and animals, plants cannot escape from drought, extreme temperatures, salinity, ultraviolet (UV) radiation, nutrient deficiency or attacks by insects and pathogens. Since they are rooted in one place, survival depends entirely on their ability to sense environmental changes and rapidly activate internal defence mechanisms.

Scientists classify plant stress into abiotic stress and biotic stress. Abiotic stresses arise from unfavourable environmental conditions such as drought, heat, cold, salinity, flooding, nutrient imbalance and excessive UV radiation. In contrast, biotic stresses result from living organisms including insects, fungi, bacteria, viruses and herbivorous animals. Both forms of stress disrupt normal physiological processes, reducing photosynthesis, disturbing water balance and increasing the formation of harmful reactive oxygen species (ROS), which can damage cellular components if not effectively controlled.

Plants, however, are far from helpless. They possess highly sophisticated sensing and signalling systems that detect stress within minutes. Once a stress signal is perceived, a cascade of physiological and biochemical responses is initiated. Plant hormones such as abscisic acid (ABA), jasmonic acid (JA) and salicylic acid (SA) act as internal messengers, activating genes responsible for defence and adaptation. These signalling pathways stimulate the production of protective proteins, antioxidant enzymes and specialized metabolites that help plants tolerate adverse conditions.

Interestingly, the compounds produced during these stress responses are often the same molecules responsible for the medicinal value of many plants. Instead of viewing stress merely as a threat, plants transform it into an opportunity to strengthen their chemical defence system. This remarkable ability to convert environmental challenges into biochemical resilience explains why medicinal and aromatic plants often become richer in valuable phytochemicals when exposed to carefully managed levels of stress.

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The Hidden Chemical Factory: How Plants Turn Stress into Medicine

At first glance, stress appears to be harmful to plants. However, plants have evolved an extraordinary survival strategy that transforms adversity into strength. When exposed to environmental or biological stress, plants do not merely endure the challenge, they actively reorganize their metabolism to produce a wide range of protective molecules known as secondary metabolites. Unlike primary metabolites such as carbohydrates, proteins and lipids, which are essential for growth and reproduction, secondary metabolites are produced mainly to enhance survival under challenging conditions.

Stress signals trigger a complex network of biochemical pathways within plant cells. Environmental stresses such as drought, salinity, heat and ultraviolet radiation often lead to the excessive production of reactive oxygen species (ROS). While ROS can damage proteins, lipids and DNA, they also act as important signalling molecules that activate defence-related genes. In response, plants increase the synthesis of antioxidant compounds and other protective phytochemicals that help neutralize oxidative damage and improve stress tolerance.

Many of these stress-induced compounds are the very molecules responsible for the medicinal properties of plants. Phenolic compounds and flavonoids act as powerful antioxidants that protect plant cells from oxidative stress. Terpenoids and essential oils help repel insects, inhibit pathogens and reduce damage caused by environmental stress. Alkaloids function as natural defence chemicals against herbivores and microbial infections, while tannins protect plant tissues by reducing feeding by insects and limiting pathogen invasion. Although these compounds evolved primarily to ensure plant survival, they have become valuable to humans because of their antioxidant, antimicrobial, anti-inflammatory and therapeutic activities.

Interestingly, plants do not continuously produce these compounds at maximum levels. Synthesizing secondary metabolites requires considerable energy and resources. Therefore, plants carefully regulate their production according to environmental conditions. Under favourable conditions, resources are mainly allocated to growth and reproduction. However, when plants perceive stress, their metabolic priorities shift from growth towards defence, resulting in enhanced accumulation of bioactive compounds. This dynamic balance explains why moderate stress often increases the concentration of medicinal compounds, whereas severe or prolonged stress may eventually impair plant growth and reduce both biomass and phytochemical yield.

This remarkable ability to convert environmental challenges into chemical defence demonstrates the extraordinary adaptability of plants. It also explains why medicinal plants growing under different climatic conditions or cultivation practices may vary significantly in their phytochemical composition and medicinal quality. Understanding these responses provides valuable opportunities for developing cultivation strategies that optimize not only crop yield but also the concentration of therapeutically important compounds.

Did You Know?

Medicinal compounds are not produced for humans.

Plants synthesize alkaloids, flavonoids, terpenoids, phenolics and other secondary metabolites to defend themselves against drought, heat, insects and diseases. Humans later discovered that many of these same compounds possess remarkable medicinal properties.

Stress by Stress: How Different Challenges Shape Medicinal Compounds

Plants may face different types of stress throughout their life cycle, and each stress triggers a unique set

of physiological and biochemical responses. While the primary objective is survival, these responses often lead to the enhanced production of valuable secondary metabolites. However, the intensity and duration of stress are critical. Moderate stress frequently stimulates the accumulation of bioactive compounds, whereas severe or prolonged stress can suppress growth, reduce photosynthesis and ultimately lower both yield and phytochemical production.

Drought Stress: Conserving Water, Boosting Defences

Drought is one of the most common environmental stresses affecting medicinal and aromatic plants. Water deficiency reduces cell expansion, limits photosynthesis and causes oxidative stress. To cope with these adverse conditions, plants activate antioxidant defence systems and increase the synthesis of phenolic compounds, flavonoids and, in several aromatic species, essential oils. These compounds help protect cells from oxidative damage and improve the plant's ability to tolerate dehydration.

Research has shown that controlled water deficit can increase the concentration of bioactive compounds in several medicinal plants, although the response varies among species and cultivars. In aromatic plants such as rosemary, thyme and sage, moderate drought has often been associated with higher essential oil concentration, while in some medicinal plants it enhances the accumulation of phenolic antioxidants (Ramakrishna and Ravishankar, 2011; Punetha *et al*., 2022).

Heat Stress: Turning up the Chemical Shield

High temperatures disturb membrane stability, enzyme activity and photosynthesis. As heat stress increases the production of reactive oxygen species (ROS), plants strengthen their antioxidant defence by synthesizing protective metabolites such as flavonoids, carotenoids and phenolic compounds. These molecules act as natural "chemical shields," protecting cellular structures from oxidative injury. In several medicinal and aromatic plants, elevated temperatures have been reported to influence both the quantity and composition of essential oils, although the magnitude and direction of the response depend on the species and growing conditions (Pradhan *et al*., 2024).

Salinity Stress: Surviving in Salty Soils

Excess salts create both water stress and ion toxicity, making it difficult for plants to absorb water and maintain normal metabolism. To survive, plants accumulate osmoprotective compounds and increase the production of antioxidants, phenolics and flavonoids that help minimize oxidative damage. Several studies have demonstrated that medicinal plants exposed to moderate salinity may accumulate higher levels of certain secondary metabolites, while excessive salinity generally suppresses growth and productivity.

Ultraviolet (UV) Radiation: Nature's Sunscreen

Sunlight is essential for plant growth, but excessive UV-B radiation can damage DNA, proteins and cell membranes. Plants respond by producing flavonoids and other phenolic compounds that absorb harmful UV rays and reduce oxidative stress. These compounds function much like a natural sunscreen, protecting sensitive tissues from radiation damage. Interestingly, many of these UV-protective compounds are also recognized for their strong antioxidant activity and contribute to the medicinal value of numerous herbs.

Insect Attack: Fighting Back with Chemistry

When insects feed on leaves or stems, plants immediately activate defence signalling pathways involving hormones such as jasmonic acid. This stimulates the production of bitter alkaloids, terpenoids and volatile compounds that deter herbivores or attract the natural enemies of insect pests. In aromatic plants, some volatile compounds released during insect attack not only repel pests but also serve as signals to neighbouring plants, enabling

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them to activate their own defence systems before being attacked. This sophisticated chemical communication demonstrates that plants actively respond to biological threats rather than remaining passive.

Pathogen Attack: Building a Chemical Defence Barrier

Fungi, bacteria and viruses pose a constant threat to plant survival. In response, plants synthesize antimicrobial compounds, including phytoalexins, phenolics and other defensive metabolites that restrict pathogen growth and strengthen cell walls. Many medicinal plants owe part of their antimicrobial properties to these naturally produced defence compounds. Scientists continue to investigate these stress-induced metabolites as promising sources of new pharmaceutical agents.

From Stress to Success: Can Farmers Improve Medicinal Quality?

Understanding how medicinal plants respond to environmental stress has opened new possibilities for producing high-quality herbal raw materials. Modern research suggests that carefully managed or controlled stress, often referred to as elicitation, can stimulate the accumulation of valuable secondary metabolites in certain medicinal and aromatic plants. However, this does not mean that exposing crops to severe stress will always produce better-quality herbs. The response depends on the plant species, the type and intensity of stress, the stage of crop growth and the duration of exposure.

Among the various approaches, regulated deficit irrigation has received considerable attention. Instead of supplying excess water throughout the crop cycle, controlled irrigation during specific growth stages may encourage the synthesis of phenolics, flavonoids and essential oils in some medicinal and aromatic crops. Similarly, environmental factors such as light intensity, temperature and nutrient management can influence phytochemical accumulation. The objective is not to stress plants to the point of damage but to create conditions that activate their natural defence pathways while maintaining healthy growth.

Protected cultivation systems, including shade nets and greenhouses, also provide opportunities to regulate environmental conditions more precisely. By managing light, temperature and irrigation, growers can influence both crop productivity and the concentration of bioactive compounds. Such approaches are increasingly being explored for high-value medicinal and aromatic crops, where quality is often as important as yield.

It is equally important to recognize that excessive stress can be harmful. Severe drought, prolonged salinity or extreme temperatures may reduce photosynthesis, inhibit plant growth and decrease biomass, ultimately lowering the total production of medicinal compounds. Therefore, successful cultivation depends on achieving a careful balance between maximizing plant growth and enhancing phytochemical quality. Scientific cultivation practices, supported by ongoing research, are essential to identify the optimum stress levels for each crop.

As demand for standardized herbal products continues to increase, understanding plant stress physiology will become an important tool for farmers, researchers and the herbal industry. Producing medicinal plants rich in bioactive compounds requires not only good agronomic practices but also a sound understanding of how plants naturally respond to their environment.

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Table 1. Stress-induced enhancement of secondary metabolites in medicinal and aromatic plants

Plant species	Stress type	Enhanced secondary metabolite	Primary application
Lemongrass	Moderate drought	Citral	Essential oil quality and aromatherapy
Rosemary (*Salvia rosmarinus*)	Water deficit	Phenolics and essential oils	Antioxidant activity and food preservation
Peppermint (*Mentha × piperita*)	Water deficit	Menthol	Flavoring, Pharmaceuticals & Cosmetics
Periwinkle (*Catharanthus roseus*)	Drought / Elicitation	Indole alkaloids (Vinblastine/Vincristine)	Anticancer compounds
Sweet Wormwood (*Artemisia annua*)	Drought / UV	Artemisinin	Antimalarial drug

Conclusion

Plants have transformed stress into one of nature's most remarkable survival strategies. Faced with drought, heat, salinity, ultraviolet radiation or biological attacks, they respond by producing an array of protective secondary metabolites that enhance their resilience. These same compounds including phenolics, flavonoids, alkaloids, terpenoids and essential oils form the foundation of many medicines, herbal products and natural health-promoting formulations used by humans today. Research over the past decades has revealed that moderate, well-managed stress can enhance the production of these valuable phytochemicals in many medicinal and aromatic plants, while excessive stress often compromises both growth and quality. This understanding has shifted the focus of cultivation from maximizing yield alone to optimizing both yield and phytochemical quality.

As agriculture moves toward sustainability and the demand for standardized herbal products continues to grow, integrating knowledge of plant stress physiology into cultivation practices offers exciting opportunities. By understanding when, how and to what extent plants respond to stress, researchers and growers can work together to produce medicinal crops of superior quality while maintaining sustainable production systems. In the plant kingdom, stress is not merely a challenge, it is often the trigger for nature's most powerful medicines.

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Why Young People are Leaving Farming – Can Extension Education Bring Them Back?

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Young people are increasingly moving away from farming, raising concerns about the future of agriculture and food production. Many of them see farming as a labour-intensive occupation with limited income and fewer opportunities compared with other careers. Lack of access to land, credit, information, and other resources also makes it difficult for young people to enter agriculture. At the same time, high youth unemployment shows the need to create more attractive employment opportunities in the agricultural sector. This article examines how agricultural extension education and skill development can encourage young people to take up farming and related activities. Training in modern farming methods, entrepreneurship, digital technologies, business management, and marketing can improve their knowledge, confidence, and income opportunities. Extension services can also help youth identify profitable enterprises and connect with markets. However, training alone cannot solve the problem; access to resources, supportive policies, and opportunities for youth empowerment are also necessary. A youth-focused extension approach can therefore help present agriculture as a modern, rewarding, and profitable career option.

1.Introduction

Agriculture is facing an important challenge today: the farming population is getting older, while fewer young people are choosing agriculture as a career. Many young people are moving towards towns and cities in search of jobs and better opportunities. Although agriculture continues to play a major role in food security and economic development, the participation of youth in the sector remains low. If this trend continues, it could affect the future of farming and the development of rural communities.

At the same time, youth unemployment remains a serious concern, particularly in low- and middle-income countries. This creates an interesting situation where many young people are looking for employment, while agriculture needs a younger and more energetic workforce (Begho & Daubry, 2025). Understanding why young people are moving away from agriculture is therefore important. It is equally important to explore whether agricultural extension education and skills training can help make farming a more attractive career for the younger generation.

2. Why Are Young People Moving Away from Agriculture?

Before considering how to bring young people back into farming, it is important to understand what is discouraging them. Previous studies suggest that youth participation in agriculture is affected by several factors, including negative perceptions about farming, limited access to resources, and a lack of opportunities for empowerment.

2.1. Negative Perceptions of Agriculture Among Youth

Many young people still associate farming with hard physical work, low income, and traditional methods. As a result, agriculture is often not viewed as a promising career or a pathway to financial success (Consentino *et al*., 2023). This traditional image of farming does not match the expectations of a generation that is familiar with digital technology and interested in modern, innovative, and financially rewarding careers.

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Changing this perception is therefore important. Young people need to see that agriculture is not limited to traditional crop production. It can also provide opportunities in areas such as agribusiness, food processing, digital agriculture, marketing, and other value-added activities.

2.2. Limited Access to Land and Credit

Negative perceptions are only part of the problem. Young people who are genuinely interested in agriculture often face practical difficulties when trying to enter the sector. Access to important resources, particularly land and credit, remains a major challenge (Geza *et al*., 2021).

Without suitable land or sufficient capital to start a farm or agricultural enterprise, many young people find it difficult to turn their interest into a livelihood. As a result, they may choose other employment options that appear easier to access.

2.3. Lack of Opportunities for Youth Empowerment

Young people in rural areas may also have limited opportunities to participate in agricultural decision-making and development activities. Studies from South Africa indicate that inadequate infrastructure, weak policy implementation, and insufficient youth-focused support can restrict their involvement in agriculture (Geza *et al*., 2022).

When young people are not given enough opportunities to participate, lead, or make decisions, they may feel that agriculture does not provide them with a meaningful future. Creating stronger support systems that recognize youth as important participants in agriculture is therefore essential.

3. Can Extension Education Encourage Youth to Return to Agriculture?

Agricultural extension services have traditionally connected farmers with agricultural research, technologies, and information. However, their role can be expanded to address the changing needs of young people. Extension services can become an important source of education, guidance, and support for youth who are interested in agriculture.

Evidence from different youth training programmes suggests that well-designed education and skills development can improve young people's participation in agriculture. Instead of focusing only on farming techniques, extension programmes should also help youth understand business opportunities, markets, technology, and entrepreneurship.

3.1. Importance of Skills Training

One important question is whether training can actually improve employment opportunities for young people in agriculture. Evidence from low- and middle-income countries suggests that it can. Training programmes that combine modern agricultural practices with business management and practical skills have been found to improve employment and income opportunities among youth (Maïga *et al*., 2020).

When young people have the right knowledge and practical skills, they may feel more confident about entering agriculture. Training can also reduce some of the uncertainty associated with farming and help them make better decisions about agricultural enterprises.

3.2. Factors Influencing Youth Participation

The success of extension programmes also depends on whether young people are interested in participating. Research on youth-in-agriculture programmes in Ondo State, Nigeria, shows that participation is influenced by socioeconomic conditions, access to information, and how profitable young people believe the programme will be (Adesina & Favour, 2016).

Therefore, extension programmes should go beyond simply teaching young people how to farm. They should also show them how agriculture can generate income. Demonstrating successful enterprises, providing market information, and explaining

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business opportunities can make such programmes more relevant and attractive to youth.

4. The Way Forward: Agribusiness and Youth Empowerment

If extension education is one way to encourage young people to enter agriculture, agribusiness can provide them with a wider range of opportunities. Agriculture should not be presented only as subsistence farming. Instead, young people should be encouraged to look at agriculture as a business that includes production, processing, marketing, value addition, and other activities along the value chain (Begho & Daubry, 2025).

To achieve this, extension programmes need to focus on areas that match the interests and aspirations of today's youth.

- **Technological integration:** Young people can be introduced to digital tools, modern agricultural technologies, and climate-smart practices that can make farming more efficient and attractive (Consentino *et al*., 2023).
- **Business management:** Training should include entrepreneurship, financial management, market linkages, and business planning so that youth can better understand how to develop profitable agricultural enterprises (Maïga *et al*., 2020).
- **Policy advocacy and empowerment:** Young people should also be encouraged to participate in groups and development activities that can help them access important resources such as land and credit (Geza *et al*., 2022).

5. Conclusion

The movement of young people away from agriculture is not necessarily because they lack the ability or interest to participate. Rather, it is closely linked to limited opportunities, inadequate resources, and the perception that farming does not provide a promising future. Many young people are looking for careers that offer better income, innovation, and opportunities for personal and professional growth.

Agricultural extension education can play an important role in changing this situation. By moving beyond traditional advisory services and providing training in agribusiness, entrepreneurship, technology, and market opportunities, extension services can help young people see agriculture in a different way. However, education and training need to be supported by better access to land, credit, infrastructure, and appropriate policies.

A stronger focus on youth-oriented extension programmes can help make agriculture more modern, profitable, and attractive. Encouraging young people to view farming not as a last resort but as a viable business and career can contribute to stronger rural communities and a more sustainable future for agriculture.

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Modern Genomics Transforming Pulse Improvement in India

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Pulse crops are an important component of India's food and nutritional security providing an inexpensive source of dietary protein, improving soil fertility through biological nitrogen fixation and sustainable farming systems. However, despite their importance, pulse productivity is still constrained by diseases, insect pests, drought, heat stress and other environmental factors. Conventional breeding has successfully developed improved cultivars, but this process is slow, and often less effective for complex traits controlled by multiple genes. The advent of modern genomics has revolutionised the improvement of pulses, enabling breeders to identify, track and harness desirable genes with a level of precision never before possible. The application of molecular marker technologies such as marker-assisted selection (MAS), genome-wide association studies (GWAS), genomic selection (GS) and high-throughput SNP genotyping has accelerated the development of improved pulse varieties with better resistance to biotic and abiotic stresses, higher yield and enhanced nutritional quality. Genomics-assisted breeding has been successfully employed in India for improvement of major pulse crops such as pigeonpea, chickpea, mungbean, lentil and urdbean by identifying genes associated with sterility mosaic disease, Fusarium wilt, yellow mosaic disease, drought tolerance and other traits of economic importance. Recent advances in whole-genome sequencing, pan-genomics, bioinformatics and artificial intelligence allow rapid gene discovery, precise selection and genomic prediction, thus further strengthening breeding programmes. These cutting edge genomic technologies, when integrated with the traditional breeding methods, are helping in developing climate-resilient, high-yielding and nutritionally enriched pulse varieties, which will help in sustainable agriculture, improving the livelihood of farmers and long-term food and nutritional security of India.

Introduction

Pulses form the backbone of India's agricultural economy and nutritional security, providing a low cost and sustainable source of dietary protein, essential amino acids, vitamins, minerals and dietary fibre to millions of people. Apart from their nutritional significance, pulse crops also contribute to sustainable agriculture through biological nitrogen fixation, enhanced soil fertility and less reliance on synthetic nitrogen fertilizers. They are an integral part of diverse cropping systems, improving soil health, enhancing biodiversity and productivity of subsequent cereal crops. India is the world's biggest producer, consumer and importer of pulses, growing major crops such as chickpea (*Cicer arietinum*), pigeonpea (*Cajanus cajan*), mungbean (*Vigna radiata*), urdbean (*Vigna mungo*), lentil (*Lens culinaris*) and field pea (*Pisum sativum*). Despite the largest acreage of pulse cultivation, the national average productivity is below the global average due to frequent outbreaks of diseases and insect pests, recurrent droughts, heat stress, erratic rainfall and the increasing impacts of climate change (FAOSTAT, 2025; Ministry of Agriculture & Farmers Welfare, 2025).

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Over the decades, conventional breeding has played a key role in developing superior pulse varieties with higher yield, disease resistance and adaptability. However, traditional breeding mainly relies on phenotypic selection, which are often affected by environmental factors, and requires several generations of field evaluation before superior genotypes are identified. Thus, the development of varieties with complex traits such as drought tolerance, climate resilience, and durable disease resistance is a long and resource-intensive process. Recent advances in molecular genetics, genomics and high-throughput sequencing technologies have revolutionized crop improvement by allowing breeders to identify desirable genes directly at the DNA level and to greatly improve the precision and efficiency of selection.

Molecular Markers: The Backbone of Genomics-Assisted Breeding:

Molecular markers are identifiable differences in DNA sequence at specific locations in the genome. They are genomic landmarks that allow researchers to detect genetic diversity, map traits of economic importance and track the inheritance of desirable alleles in breeding programmes. Unlike morphological or biochemical markers, molecular markers are not influenced by environmental conditions, developmental stage and plant physiology and are therefore very reliable tools for crop improvement and genetic analysis. The use of these tools has revolutionized modern plant breeding by enabling early generation selection, shortening breeding cycles and increasing the chances of developing superior cultivars (Collard & Mackill, 2008).

Over the past three decades, several classes of molecular markers have been developed and successfully applied in pulse breeding. Early marker systems such as Restriction Fragment Length Polymorphisms (RFLPs), Random Amplified Polymorphic DNA (RAPD), Amplified Fragment Length Polymorphisms (AFLPs) and Simple Sequence Repeats (SSRs) made a great jump in genetic mapping and diversity studies. More recently, Single Nucleotide Polymorphism (SNP) markers have become the preferred choice due to their abundance throughout the genome, high reproducibility, codominant inheritance and compatibility with automated high-throughput genotyping platforms. Technologies such as Diversity Arrays Technology (DArT), genotyping-by-sequencing (GBS), SNP arrays and whole-genome resequencing have further accelerated gene discovery and precision breeding in pulse crops.

Importance of Molecular Markers for Pulse Improvement:

The major advantage of molecular markers is the ability to detect desirable genes or quantitative trait loci (QTLs) without waiting for expression of the trait in the field. This allows breeders to make accurate decisions at the seedling stage and reduces the time, costs and uncertainty associated with traditional breeding. Molecular markers have emerged as a significant tool in modern breeding programs for pulses to develop improved varieties with better resistance to biotic and abiotic stresses, along with high yield and improved grain quality. Molecular markers are now widely used to enhance several economically important traits in pulse crops, such as:

- Resistance to fungal, bacterial, and viral diseases
- Resistance to insect pests
- Drought, heat, and salinity tolerance
- Early flowering and maturity
- Seed size, colour, and cooking quality
- Enhanced protein, iron, and zinc content
- Grain yield and yield stability under diverse environments

The integration of molecular markers with genome-wide association studies (GWAS), genomic selection, pan-genomics, transcriptomics and artificial

intelligence has brought a new era of genomics-assisted breeding (Varshney *et al.*, 2021; Bohra *et al.*, 2023). These technologies are helping researchers to identify better alleles in a faster way, speed up the development of varieties and bring out climate resilient, high yielding and nutrient-rich pulse cultivars that can meet the increasing food and nutritional needs of India.

Marker-Assisted Selection: A Powerful Breeding Tool

Marker-assisted selection (MAS) is a modern breeding method that uses DNA markers linked to desirable genes to select superior plants at the seedling stage, without having to wait for the trait to be expressed in the field. This technology provides more precise selection, shorter breeding cycles, and reduces the cost and time to develop improved varieties. The complete workflow of MAS is shown in Figure1. MAS has been successfully used to introduce resistance to *Fusarium wilt* and *Ascochyta blight* in chickpea, Sterility Mosaic Disease (SMD) in pigeonpea and Yellow Mosaic Disease (YMD) in mungbean and urdbean in India. Due to its precision and efficiency, MAS has become indispensable for the development of pulse varieties with higher yield potential, disease resistance and climate resilience (Collard & Mackill, 2008; Varshney *et al.*, 2021; Bohra *et al.,* 2023).

India has successfully used Marker-Assisted Selection (MAS) in pulse breeding programmes to speed up the development of improved varieties. In chickpea, MAS has been used to introgress resistance to *Fusarium* wilt and *Ascochyta* blight and in pigeonpea, it has helped to identify Sterility Mosaic Disease (SMD) resistant genotypes. Similarly, molecular markers have also been used to develop resistant varieties of mungbean and urdbean against Yellow Mosaic Disease (YMD). MAS is being increasingly used to develop resistance to diseases, drought tolerance, early maturity, seed quality, nutritional traits and yield. MAS in conjunction with advanced genomic tools like GWAS, genomic selection and pan-genomics are accelerating the development of climate-resilient high-yielding pulse varieties for sustainable agriculture and enhanced food security (Thudi *et al.*, 2016; Saxena *et al.*, 2017; Varshney *et al.*, 2021; Bohra *et al.*, 2023).

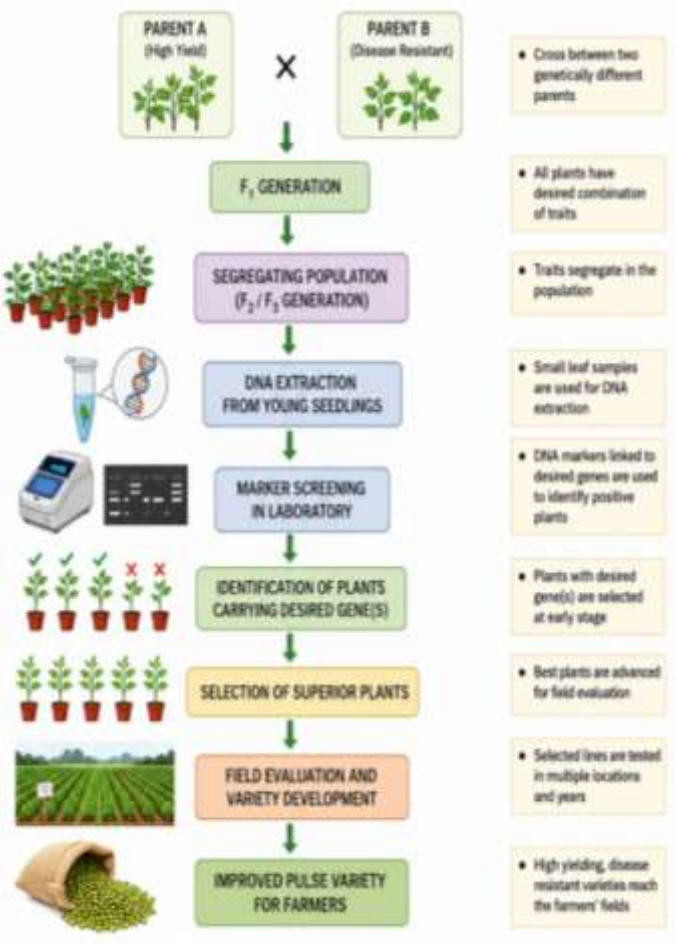

Figure 1. Workflow of marker-assisted selection to demonstrate how DNA markers allow for early identification of desirable plants carrying target genes for disease resistance, stress tolerance and yield improvement.

Genome-Wide Association Studies (GWAS) and Modern Pulse Improvement

Recent advances in whole genome sequencing and high density single nucleotide polymorphism (SNP) markers have made Genome Wide Association Studies (GWAS) a powerful tool to identify genomic regions controlling complex agronomic traits. GWAS has enabled the identification of genes and QTLs for traits such as flowering time, seed size, yield, drought

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tolerance, and resistance to major diseases in pulse crops including pigeonpea, chickpea, mungbean, and lentil through the use of natural genetic variation present in diverse germplasm collections (Varshney *et al.,* 2021; Bohra *et al.,* 2023). The molecular markers identified through GWAS are being increasingly used in genomics-assisted breeding programmes to develop superior pulse varieties in a short duration.

Genomic Selection: The future of pulse breeding

Genomic selection (GS) utilizes thousands of markers across the entire genome, and marker-assisted selection utilizes a few major genes. Advanced statistical models can predict individual plant breeding values from their genomic profile. This approach is especially appropriate for complex traits such as grain yield, nutritional quality and tolerance to multiple environmental stresses, that are under the control of many genes with small individual effects. GS can be used for accurate selection at early generations, thereby reducing breeding time, increasing selection efficiency and accelerating genetic gain. The combination of genomic selection with high-throughput phenotyping, artificial intelligence (AI) and advanced bioinformatics is expected to further revolutionize pulse breeding and assist the development of climate-resilient, high-yielding cultivars for sustainable agriculture (Xu et al., 2017; Varshney et al., 2021; Crossa et al., 2017).

Success Stories in Indian Pulse Research

Indian agricultural research institutions facilities have made notable progress in the use of molecular techniques for pulse improvement. National initiatives involving ICAR institutes, agricultural universities and foreign research groups have generated important genetic resources of important pulse crops. Availability of reference genome sequences for pigeonpea and chickpea have facilitated gene discovery and marker development. Today, high-density SNP arrays, genotyping platforms and bioinformatics tools are enabling precision breeding efforts across the nation. These advances have enhanced the capacity of breeders to combine resistance to biotic and abiotic stressors with high production potential. Some of the notable Indian success stories on pulses are:

i) Pigeonpea: Breeding for Sterility Mosaic Disease Resistance

Sterility Mosaic Disease (SMD), also known as the "green plague" of pigeonpea, is one of the most damaging diseases in India, in terms of productivity. ICAR institutes and partner research groups have identified molecular markers associated with genes for SMD resistance. These markers have allowed breeders to efficiently screen breeding populations and accelerate resistant line development. Marker-assisted breeding has shortened the time required to identify resistant.

ii) Chickpea: Enhancing Resistance to Fusarium Wilt

Fusarium wilt is one of the major constraints in the cultivation of chickpea in most of the pulse growing regions of India. Researchers used genetic mapping and marker-assisted selection to identify DNA markers tightly linked to wilt resistance genes. These markers have been employed in breeding programmes for the rapid identification of resistant plants and the development of improved chickpea varieties with greater disease resistance and consistent field yields.

iii) Mungbean: Improving Resistance to Yellow Mosaic Disease

Mungbean Yellow Mosaic Disease (MYMD) is a widespread disease in India, causing considerable losses in mungbean production. Molecular markers associated with resistance genes have made it possible to identify and select resistant breeding lines. The use of marker-assisted selection in mungbean improvement programmes has enhanced the efficiency of breeding and has helped in

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developing varieties better adapted to disease-prone environments.

Molecular Markers: Benefits in Pulse Breeding

"Pulse breeding" will be driven by the integration of genomics, phenomics, artificial intelligence and sophisticated breeding techniques in the future. Molecular technologies are becoming more available to breeding programs as the costs of DNA sequencing and genotyping continue to decrease. New technologies like gene editing, haplotype-based breeding and genomic prediction will continue to increase the efficiency of breeding. The integration of conventional breeding knowledge with molecular technologies is expected to speed up the development of climate resilient, high-yielding and nutritionally superior varieties of pulses. Advantages of molecular markers in pulse breeding are as follows:

i. Faster development of improved varieties
ii. Early selection at seedling stage
iii. Improved precision in breeding
iv. Reduced dependence on environmental screening
v. Efficient pyramiding of multiple resistance genes
vi. Enhanced resilience to climate change

Short Summary

Molecular markers have transformed the breeding of pulse crops, providing plant breeders with accurate tools to select for desirable genes that confer disease resistance, stress tolerance and increased yield. Technologies such as marker-assisted selection, genome-wide association studies and genomic selection are useful for breeders to develop superior varieties of pigeonpea, chickpea and mungbean and pulse crops more efficiently reducing breeding time and increasing the efficiency of crop improvement programmes. With the ever increasing research infrastructure and genomic resources in India, molecular marker-assisted breeding will be instrumental in ensuring food and nutritional security through development of improved pulse varieties for future generations.

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Fading Shorelines: Understanding the Coastal Erosion, Its Impacts and Sustainable Management

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Coastal zones represent highly dynamic interfaces between terrestrial and marine environments, supporting diverse ecosystems, human settlements, economic activities, and critical infrastructure. However, these environments are increasingly subjected to shoreline instability and coastal erosion arising from the complex interaction of natural coastal processes and anthropogenic interventions. Variations in wave climate, tidal dynamics, sediment transport, extreme events, sea-level rise, and changes in land-use patterns can substantially modify coastal morphology and sediment budgets, while structures such as ports, seawalls, groynes, and reclamation works may further disrupt natural sediment circulation. The resulting shoreline retreat poses significant environmental, socio-economic, and infrastructural risks, particularly in densely populated and economically important coastal regions. Consequently, a comprehensive understanding of the processes, drivers, impacts, monitoring techniques, and management options associated with coastal erosion is essential for developing scientifically sound and sustainable strategies for coastal resilience and long-term coastal zone management.

Introduction

Coastal erosion, also termed shoreline retreat, is the process of persistent removal of sediments or rocks from the shoreline, resulting in the landward migration of the coast. It is a natural geomorphic phenomenon driven by dynamic coastal processes including waves, tides, currents, and wind-induced circulation. Globally, coastal erosion poses a significant threat to infrastructure, economic activities, ecosystems, and human settlements concentrated along coasts. Recent studies estimate that nearly 70% of sandy beaches worldwide are undergoing erosion, with considerable variation in rates and patterns depending on regional coastal geomorphology and climatic conditions (Luijendijk et al., 2018).

From an Indian perspective, coastal erosion is an equally pressing issue given the country's extensive coastline of about 11098.81 km, encompassing nine states and two union territories. The Indian coastline supports dense populations, industrial zones, ports, tourist destinations, and ecologically sensitive areas such as mangroves, coral reefs, and estuarine ecosystems. According to the National Centre for Coastal Research (NCCR), around 34% of the Indian mainland coastline is experiencing erosion, with particularly severe impacts along the eastern coast, including Odisha, West Bengal, and parts of Andhra Pradesh, and along the western coast in Kerala and parts of Karnataka (MoEFCC, 2019). The vulnerability of these regions is compounded by tropical cyclones, monsoonal wave regimes, sea-level rise, and unplanned coastal development. For instance, Odisha's Satabhaya villages have been completely lost to erosion, forcing the relocation of entire communities inland (https://earthjournalism.net/stories/sea-erosion-affecting-lives-and-livelihoods-in-odisha).

Therefore, understanding coastal erosion processes and developing robust management frameworks is crucial for India's sustainable coastal zone

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development, disaster risk reduction, and ecological conservation goals.

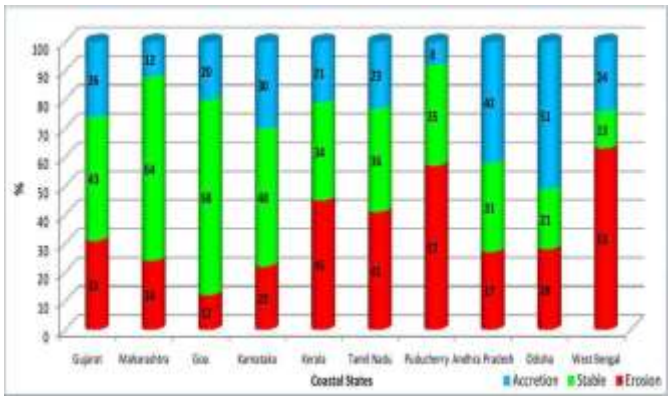

Figure 1. Shoreline change status of Indian coastal states in percentage (Kankara et al., 2018)

Causes and Processes of Coastal Erosion

Coastal erosion arises due to a complex interplay of natural forces and anthropogenic activities that alter sediment dynamics and geomorphological equilibrium. Natural causes include wave action, where breaking waves exert shear and hydraulic forces on coastal sediments. The impact depends on wave energy, height, period, and angle of approach. In areas with predominant oblique wave approach, longshore currents are generated, leading to littoral drift that transports sediments alongshore, causing erosion at one site and accretion at another. High-energy wave events such as cyclonic storms or swell waves increase offshore sediment transport, resulting in rapid beach lowering and landward retreat (Komar, 1998).

Figure 2. Shoreline change map along Indian coast, 1990-2016 (Kankara et al., 2018)

Tidal currents, especially in estuarine and tidal inlet regions, contribute to erosion by scouring channel banks and transporting sediments seaward or along the coast. In deltas and estuaries, tidal asymmetry can result in net sediment export, leading to erosion of tidal flats and delta fronts. Sea-level rise driven by climate change further aggravates erosion by increasing water depths nearshore, enhancing wave energy reaching the coast and causing submergence of low-lying beaches and dunes (Nicholls & Cazenave, 2010). Additionally, episodic events such as tsunamis and storm surges lead to catastrophic erosion by overwashing coastal barriers and stripping large sediment volumes in short durations.

Anthropogenic causes significantly accelerate natural erosion rates. Coastal engineering structures such as seawalls, groynes, breakwaters, and jetties, constructed for protection or navigation, often interfere with longshore sediment transport pathways. For example, groynes trap sediments on their updrift side, causing sediment starvation and increased erosion on the downdrift side. Seawalls reflect wave energy, often leading to scouring at their toe, progressive lowering of adjacent beach profiles, and eventual failure of the structure itself if not adequately designed (Dean & Dalrymple, 2002).

River damming upstream reduces sediment fluxes reaching deltas and coasts. The global construction of dams has decreased sediment supply to many deltaic coasts by up to 70%, resulting in delta subsidence and erosion (Syvitski et al., 2005). Sand mining from beaches, riverbeds, and nearshore areas for construction depletes natural sediment budgets and lowers beach and riverbed levels, destabilising banks and shorelines (UNEP, 2019). Coastal land reclamation, port dredging, and indiscriminate mangrove clearance for aquaculture or urban expansion disrupt sediment dynamics and the natural buffering capacity of coasts against erosion and wave attack.

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Processes of Sediment Transport and Erosion Mechanisms

Coastal erosion is governed by sediment transport processes operating in different spatial and temporal scales. The cross-shore sediment transport involves movement perpendicular to the shoreline, largely driven by wave-induced undertow and storm surge flows. During calm conditions, sediments move landward, causing beach accretion, while storm conditions reverse the process, resulting in erosion and offshore bar formation.

Longshore sediment transport (littoral drift) is driven by oblique wave incidence generating longshore currents, transporting sediments parallel to the shore. Interruptions in this transport due to natural features or human structures cause erosion in downdrift areas. Tidal prism-induced currents near tidal inlets cause scouring and bank erosion, while fluvial inputs modify nearshore sediment budgets.

On a micro-scale, sediment entrainment and erosion are controlled by grain size, sediment cohesion, bedform structures, and hydrodynamic shear stresses. Fine sediments in muddy coasts are more cohesive and resist erosion up to a critical shear stress, whereas sandy coasts are highly mobile. The interaction of waves and currents, termed wave-current interaction, amplifies bed shear stress and enhances erosion potential, especially in estuarine mouths and tidal flats (Dastgheib et al., 2018).

Impacts of Coastal Erosion

The impacts of coastal erosion are severe and multidimensional. Environmentally, erosion leads to the permanent loss of ecologically sensitive habitats such as dunes, mangroves, tidal flats, and wetlands. These ecosystems serve as natural buffers against wave attack and flooding, provide breeding grounds for fish and shellfish, and regulate coastal microclimates (Feagin et al., 2010). Loss of these ecosystems decreases biodiversity, increases coastal vulnerability to extreme events, and disrupts ecosystem services critical for coastal communities.

Socio-economically, erosion causes damage to critical infrastructure including coastal highways, railways, ports, tourism facilities, and residential buildings. In India, erosion has resulted in the loss of agricultural lands and freshwater aquifers due to saline intrusion, affecting livelihood security in states like Kerala and West Bengal (MoEFCC, 2019). In Odisha, the complete submergence of Satabhaya villages due to rapid shoreline retreat forced the displacement of hundreds of families, leading to socio-economic disruption, cultural disintegration, and loss of ancestral lands (Kumar et al., 2010). Globally, the economic costs of coastal erosion are projected to increase significantly with rising sea levels and intensifying storm events if effective adaptation measures are not implemented (Nicholls et al., 2007).

Monitoring and Assessment of Coastal Erosion

Effective management of coastal erosion requires systematic monitoring and assessment. Remote sensing and GIS techniques have revolutionised coastal monitoring by enabling multi-temporal analysis of shoreline changes over large areas. High-resolution satellite imagery, combined with georeferenced historical maps, allows accurate quantification of erosion and accretion rates, identification of erosion hotspots, and detection of morphological changes in beaches, estuaries, and tidal inlets (Savastano et al., 2024).

Field-based methods such as Differential Global Positioning System (DGPS) surveys, Real-Time Kinematic (RTK) GPS, and Total Station surveys are used for precise shoreline and beach profile measurements. Sediment sampling and granulometric analysis provide information on sediment dynamics and coastal sediment budgets. Advanced numerical modelling tools such as Delft3D, MIKE21, and SWAN are used to simulate wave hydrodynamics, sediment transport, and shoreline evolution under various scenarios, supporting engineering design and management decisions (Dastgheib et al., 2018). Incorporating

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climate change projections, sea-level rise scenarios, and extreme event simulations enhances the predictive capacity of these models for long-term coastal zone planning.

Coastal Erosion Management

Managing coastal erosion involves a combination of hard engineering solutions, soft engineering approaches, and integrated policy frameworks. Hard engineering structures, including seawalls, groynes, revetments, and offshore breakwaters, are traditionally constructed to protect infrastructure and stabilise shorelines. While effective in the short term at specific sites, these structures often cause adverse impacts such as downdrift erosion, beach narrowing, and habitat degradation if not designed and managed based on comprehensive sediment transport studies (Dean & Dalrymple, 2002).

Soft engineering approaches focus on working with natural processes. Beach nourishment, involving the addition of sediments to eroded beaches, restores beach width and recreational value while providing a buffer against storm waves. Dune stabilisation using vegetation planting and fencing enhances natural coastal defence by trapping sediments and reducing wind erosion. Ecosystem-based adaptations such as mangrove restoration, coral reef rehabilitation, and creation of living shorelines integrate ecological conservation with shoreline protection, enhancing resilience to erosion and extreme events (Alongi, 2008).

Integrated Coastal Zone Management (ICZM) is a holistic management approach that coordinates sectoral activities, environmental conservation, and community participation to achieve sustainable coastal development. India's ICZM programme, implemented with World Bank support, focuses on shoreline management plans, mangrove and wetland restoration, community-based livelihoods, and institutional strengthening for coastal governance (MoEFCC, 2019). Incorporating traditional knowledge, scientific assessments, and participatory governance is essential for effective erosion management and disaster risk reduction.

Conclusion

Coastal erosion is a natural, dynamic process that shapes coastal landscapes, but its impacts have intensified globally and in India due to anthropogenic activities and climate change. Understanding its causes, processes, and impacts is fundamental to developing effective and sustainable management strategies. Technological advances in monitoring, numerical modelling, and ecosystem-based solutions offer opportunities for integrated coastal management, enhancing resilience to erosion and protecting the livelihoods and ecosystems upon which millions depend. Given the accelerating risks posed by sea-level rise and extreme events, urgent and coordinated action is needed at local, national, and global levels to safeguard coastal zones for future generations.

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Carbon Farming: Can Farmers Be Paid for Capturing Carbon?

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For generations, farmers have been paid for what they harvest - grain, fruits, vegetables, fibre and other agricultural products. But agriculture is now beginning to offer another possible source of value. What if farmers could also earn money for improving soil health, planting trees, reducing greenhouse-gas emissions and storing more carbon on their farms?

This is the basic idea behind carbon farming.

Although carbon cannot be seen like a crop in the field, it plays an important role in agriculture and climate change. Plants absorb carbon dioxide from the atmosphere during photosynthesis and use it to grow. Part of this carbon eventually enters the soil through roots, crop residues and organic matter.

Good farming practices can help keep more carbon in the soil and vegetation. Poor management, on the other hand, can release stored carbon back into the atmosphere. Carbon farming aims to encourage practices that reduce these losses and increase the amount of carbon stored on farms.

For India, where millions of farmers cultivate relatively small holdings, this creates an important question: can climate-friendly farming also become an additional source of income?

What Is Carbon Farming?

Carbon farming refers to agricultural practices that help remove carbon dioxide from the atmosphere, store carbon in soil and plants, or reduce greenhouse-gas emissions from farming.

It is not one particular technology or farming system. It includes a range of practices such as reduced tillage, crop-residue management, compost application, cover cropping, agroforestry, improved rice-water management and better livestock-waste management.

The main idea is simple: farmers manage their land in ways that are good for both agricultural production and the climate.

How Can Farmers Store More Carbon?

Healthy soil contains organic matter, and carbon is an important part of that organic matter. Farmers can increase soil carbon by adding plant residues, compost and green manures and by reducing unnecessary disturbance of the soil.

Leaving crop residues in the field instead of burning them can return organic material to the soil. Growing cover crops between main crops can protect the surface while adding plant biomass and roots. Agroforestry can also help. Trees planted on field boundaries or within agricultural land store carbon in their trunks, branches and roots while providing fruits, timber, fodder or other useful products.

Another emerging option is biochar, a carbon-rich material produced by heating biomass under controlled conditions. When properly prepared and applied to soil, biochar can remain stable for long periods and may also improve certain soil properties.

Rice cultivation offers another opportunity. Continuously flooded rice fields can release methane, an important greenhouse gas. Improved water-

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management practices can reduce these emissions where local conditions allow. Better manure management can also reduce methane emissions from livestock systems.

How Can Carbon Farming Earn Money?

The link between carbon farming and income comes through carbon credits.

In simple terms, one carbon credit generally represents one tonne of carbon-dioxide equivalent that has been reduced, avoided or removed from the atmosphere according to an accepted method.

Suppose a group of farmers adopts new farming practices that reduce greenhouse-gas emissions or increase carbon storage. The change has to be measured against a baseline, recorded over time and verified under an accepted methodology. Once the climate benefit is verified, carbon credits may be issued and sold in a carbon market.

However, farmers should remember that adopting a climate-friendly practice does not automatically create a carbon credit. The activity must meet specific rules for measurement, additionality, monitoring and verification.

Carbon Farming in India

India is gradually developing its own carbon-market framework under the Carbon Credit Trading Scheme. The Bureau of Energy Efficiency lists agriculture among the approved sectors under the offset mechanism.

As of July 2026, approved agricultural methodologies under this mechanism include methane recovery from livestock and manure management at households and small farms, as well as emission reduction through improved management practices in rice cultivation. This is an important step because it creates a formal route for eligible agricultural projects to generate verified carbon benefits.

India has also begun empanelling accredited carbon verification agencies for the Carbon Credit Trading Scheme, including agencies accredited for agriculture under the offset mechanism. This is necessary because credible carbon markets depend on independent validation and verification.

Why Carbon Farming Matters Now

Climate change is making agriculture increasingly uncertain. Farmers are experiencing rising temperatures, irregular rainfall, drought, floods and changes in pest and disease behaviour. At the same time, soil degradation and declining organic matter are affecting long-term productivity.

Carbon farming can contribute to both climate mitigation and farm resilience. Practices that increase organic matter can improve soil structure and help the soil hold more water. Better residue management can protect the soil against erosion, while improved nutrient and water management can reduce unnecessary losses.

Interest in this approach is growing in India. In August 2026, ICAR-Indian Institute of Soil Science, Bhopal, organised a Carbon Pathshala for farmers from Vidisha district to explain carbon markets, agricultural carbon credits and regenerative practices. Farmers were introduced to minimum tillage, residue incorporation, green manuring and integrated nutrient management, along with the idea that scientifically measured climate benefits may create additional income opportunities.

The significance of such programmes is that carbon farming is moving beyond policy discussions. Farmers, scientists and project developers are beginning to examine how these ideas can work at field level.

Benefits Beyond Carbon Credits

The greatest advantage of carbon farming may actually come from benefits that farmers can see directly in their fields.

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Improved soil organic matter can increase water-holding capacity. Better residue management can reduce erosion. Crop rotation and green manuring can support soil fertility and help break pest and disease cycles. Agroforestry can provide additional products such as fruit, fodder, fuelwood and timber.

These benefits remain valuable even if the price of carbon credits changes. For this reason, farmers should ideally adopt carbon-farming practices because they improve the farm itself, with carbon-credit income treated as an additional benefit rather than the only reason for changing practices.

Why Measuring Carbon Is Difficult

Measuring carbon in agriculture is not as simple as weighing a crop after harvest.

Soil carbon varies from one location to another. It is affected by soil type, rainfall, temperature, irrigation, crop rotation, organic inputs and previous land management. To calculate a carbon benefit accurately, a project needs to know the starting condition and then measure or model how it changes over time.

Repeated soil sampling across thousands of small farms can be expensive. This is why newer carbon projects are increasingly interested in digital measurement, reporting and verification. Satellite imagery, remote sensing, GPS-based farm records, mobile applications, sensors and computer models can help monitor large areas more efficiently.

Artificial intelligence may further help analyse these large datasets, but digital tools cannot replace sound field measurements and transparent scientific methods.

Can Small Farmers Benefit?

This is one of the most important questions for India.

A farmer with a small landholding may not generate enough carbon credits individually to justify the cost of registration, monitoring and verification. Small farmers are therefore more likely to participate through aggregated projects that bring many farms together.

Farmer Producer Organisations, cooperatives, companies or specialised project developers can help organise such projects, maintain records and coordinate verification. Aggregation can reduce costs, but it also creates another important question: how much of the final carbon income will actually reach the farmer?

Farmers must clearly understand the agreement before joining a project. They should know how credits are calculated, who owns them, what costs will be deducted, how long they must continue the required practice and how payments will be shared.

Transparency will be essential if carbon farming is to earn the trust of small and marginal farmers.

What Happens to Stored Carbon Later?

Another important issue is whether the carbon remains stored for a long time.

Suppose a farmer follows practices that increase soil carbon for several years. If the field is later heavily disturbed, cleared or subjected to severe erosion, some of that stored carbon may return to the atmosphere. Carbon projects therefore have to consider permanence - whether the claimed climate benefit is likely to last.

There is also the question of additionality. A carbon credit should represent a climate benefit that would not have occurred in the same way without the project. If a farmer has already been following the same practice for many years, proving a new and additional benefit can be more complicated.

These rules may appear technical, but they are important for ensuring that carbon credits represent real environmental gains.

Things Farmers Should Be Careful About

The growing interest in carbon markets has also created the risk of unrealistic promises.

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Farmers may sometimes hear that planting trees, applying compost or reducing tillage will quickly create a large new source of income. In reality, carbon-credit earnings depend on the amount of verified emission reduction or carbon storage, project costs, verification expenses, market prices and the contract between farmers and project developers.

Before joining any project, farmers should ask simple but important questions: Who owns the credits? Who pays for monitoring and verification? How long will the agreement continue? What happens if the farmer changes the cropping system? How and when will the farmer be paid?

Clear answers to these questions are necessary before carbon farming can become a dependable income opportunity.

Carbon Farming in Horticulture

Horticulture also has considerable potential for carbon farming.

Fruit trees and plantation crops remain in the field for many years and can store carbon in woody biomass and soil. Mango, guava, citrus, pomegranate, coconut, cashew, coffee and other perennial crops can be managed with mulching, composting, cover crops, reduced soil disturbance and efficient irrigation.

Agroforestry can further combine fruit crops with useful trees and other crops. Orchard residues may be composted or, where suitable systems exist, converted into biochar rather than simply burned.

Protected cultivation can also become more climate friendly through solar energy, precision irrigation, efficient fertigation, better energy management and recycling of crop residues and greenhouse materials.

Thus, carbon farming is not limited to cereals or field crops. Orchards, plantations, livestock systems and high-value horticulture can also form part of the wider transition toward low-carbon agriculture.

The Future of Carbon Farming

Carbon farming has the potential to create a new relationship between agriculture and environmental services.

Until now, farmers have mainly been rewarded for the food and other products they sell. In the future, they may also be rewarded for improving soil, storing carbon and reducing greenhouse-gas emissions.

However, carbon farming should not be presented as a guaranteed new source of income for every farmer. Its success will depend on reliable science, transparent carbon markets, affordable monitoring systems and fair sharing of benefits.

The farmer must remain at the centre of the system.

The most successful carbon-farming projects will be those in which farmers gain in two ways: through healthier and more productive farms, and through a fair payment for the climate benefits they create.

Carbon may be invisible, but its value to agriculture is becoming increasingly visible. If the right systems are developed, the soil beneath a farmer's feet may one day become not only the foundation of crop production but also an important part of India's response to climate change.

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From Paddy Straw to Saree: An Indigenous Approach to Paddy Nursery Covering

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"Agricultural innovation does not always begin with a new invention; sometimes, it begins with a farmer making a better use of what is already available"

During our Rural Agricultural Work Experience (RAWE) field visit to Kannanur village, Chetpet Block, Thiruvanamalai district, Tamil Nadu, we came across a simple yet remarkable indigenous practice followed by many paddy farmers in the region, the use of old sarees as a temporary covering material over paddy nursery beds. The practice immediately caught our attention because the material being used was not a specialised agricultural product. It was an ordinary household textile that had been given a second purpose in the field. What appeared to be a simple practice reflected several important aspects of farming: local resource availability, practical convenience, reuse, cost consciousness and farmer led innovation. Paddy nursery establishment is a critical stage in rice production because the healthy establishment of seedlings determines the quality of planting material available for the main field. During the early stage after sowing, seeds are vulnerable to environmental disturbances, particularly rainfall. This makes the choice and management of a suitable temporary covering material an important part of nursery management.

Paddy straw as the conventional nursery covering material

Paddy straw has long been used by farmers as a nursery covering material because it is readily available within the rice production system. It is locally accessible, familiar to farmers and generally inexpensive when available on the farm. The Tamil Nadu Agricultural University (TNAU) Agritech Portal recommends the use of locally available materials such as straw and coir-pith for covering nursery beds, particularly in SRI and mat nursery systems. The material also fits natural into the farm ecosystems. Instead of purchasing a separate covering product, farmers can utilise a crop residue that is already available. This makes straw particularly attractive for farmers seeking simple and affordable nursery management practices. Paddy straw also has an advantage beyond its temporary role as a cover. As an organic crop residue, it can subsequently be managed within the agricultural system rather than being treated solely as waste. This is why paddy straw continues to be a viable choice for nursery coverings.

Why do farmers keep using straw?

Farmers' choice is affected not only by agronomists' advice but also by availability, cost, labour and experience. Paddy straw fulfills most of these criteria. Paddy farmers usually have straw readily available either in their own production system or in the neighbouring farms. It does not require any special acquisition, is familiar as material to work with and can be used anytime the need arises. Its efficiency as physical cover is another important characteristic. Straw layer can serve as a protection against disturbances at the time of seeding and, under right conditions, preserve coverage of the nursery bed. Therefore, the choice to keep using straw should be seen in the context of practical needs of farmers. Nevertheless, the very same physical property of straw makes its handling more difficult. The straw is a loose material. It has to be spread on the nursery

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bed and later on be either removed or collected when the seedlings appear. In the process of removing individual pieces could get lost around the nursery area. Therefore, handling of this material takes more physical efforts than one single piece of covering material. This does not lessen the value of the straw.

Indigenous Alternative from Kannanur Village

Our observation in this particular case was very significant in this regard. There is a practice among many farmers growing paddy in this region who use old sarees as nursery covers in an indigenous way. Saree is different from straw in the sense that straw comprises many separate units whereas the saree makes up a continuous piece. This means the farmer can spread the saree on the nursery bed and then take it away in one piece. An old saree that may no longer be suitable for household use is transformed into a functional agricultural resource. The innovation is therefore not necessarily in creating a new material. It is in creating a new use for an existing material.

Figure 1. Indigenous use of old sarees as a temporary covering material for paddy nurseries in Kannanur Village.

Saree as a Nursery covering material

The use of sarees as agricultural covering material has also been documented beyond our field observation. Researchers from the ICAR- Indian agricultural research institute (ICAR- IARI), Regional station, Aundh, Pune, documented the use of sarees by farmers as unconventional crop protection covers. Their article "Saree: An indigenous 'Desi' solution for crop protection", descries sarees as an economical and durable alternative to commercially available crop covering materials. The ICAR-IARI publication highlights that farmers have adapted old sarees for agricultural protection because commercially available covering materials can involve considerable expenditure. It also documents the durability and repeated use potential of saree-based covers.

The practice has also received attention in The Hindu Business Line, which reported on farmers using sarees to protect chilli nurseries from climatic conditions and wild animals. This provides another example of a household textile being adapted into an agricultural covering material. The fact that these documented cases exist is significant since they help demonstrate that the use of sarees in agriculture is not an isolated concept. Instead, it is one of the many cases where there have been instances of innovations among indigenous farmers, as well as the repurposing of resources. While this does not prove that sarees are better than paddy straw in the case of paddy nurseries, sarees could work well in this context too.

Practical advantages of using an old saree

One of the most apparent advantages that a saree provides is the physical design. Due to its nature as an uninterrupted cloth, it is easier to drape over the nursery bed. Its removal can also be done through simply lifting the sheet without having to pick up many individual pieces. This may help lessen the effort required in the handling of the covering material. A more significant advantage of using a

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saree is the consistency of the covering that it provides. With proper placement, the sheet can cover the nursery bed evenly. Another important advantage is that of reuse. A good saree may be cleaned, dried, and stored for future reuse.

Instead of purchasing a specialised agricultural cover, farmers may be able to make use of a household material that is already available. The practice can therefore potentially offer:

- Easy spreading and removal
- Relatively uniform coverage
- Potential reusability
- Reduced loose covering residues
- Lower dependence on specialised covering products
- Productive reuse of household textiles
- Potential reduction in handling effort

The actual economic advantage, however, will depend on the availability, durability, cleaning, storage, and number of times the material can be reused.

Straw and Saree: Complementary options

The juxtaposition (comparison) of the two materials must not be made to seem like a competition. There are definite advantages to using paddy straw. For one thing, it is a farm waste, available locally and is a known covering material. It is especially appropriate for those farmers who have enough straw available with them. Saree, on the other hand, has its own advantages. It is a continuous sheet and can possibly be reused; it could make handling easier and give another purpose to something which would have been discarded anyway. (Table 1).

Table 1. Comparative characteristics of paddy straw and old sarees as temporary covering materials for paddy nurseries.

Characteristic	Paddy straw	Old saree
Source	Crop residue	Reused household textile
Availability	High in rice growing areas	Depends on availability of suitable old sarees
Form	Loose material	Continuous sheet
Application	Manual spreading	Unfolding and spreading
Removal	Gathering loose material	Can be lifted as one sheet
Reusability	Limited for this particular covering use	Potentially reusable
Loose residue	May remain after removal	Minimal loose covering residue
Additional material cost	Usually low when farm available	Potentially low when reused
Resource value	Organic crop residue	Productive reuse of household material

This comparison makes one point clear: The best covering material may depend on the farmer's resources and circumstances.

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Comparative Field Assessment

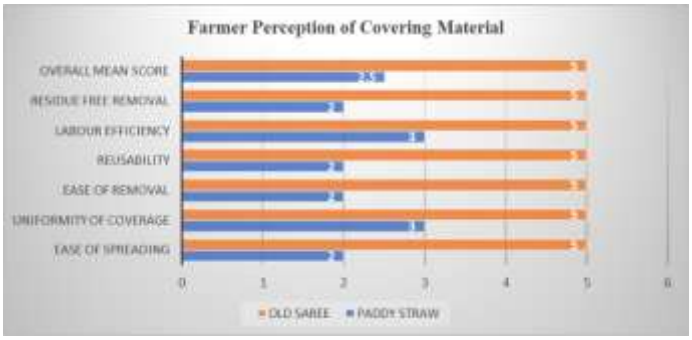

Figure 2. Comparative field assessment of paddy straw and old saree based on handling, coverage and reuse characteristics observed during the RAWE field visit at Kannanur village, Tiruvannamalai district. Scores represent a qualitative 1-5 assessment and are intended for comparative illustration, not statistical experimental results.

What We Recommend

Based on our field observation in Kannanur village and the wider documentation of sarees as agricultural covering materials, we recommend that old sarees be explored as a potential alternative temporary covering material for paddy nurseries where suitable cloth is locally available. We do not recommend immediately replacing paddy straw. Instead, we recommend documenting, evaluating, and scientifically validating the indigenous saree-covering practice already followed by farmers. This approach is important because the practice has merged from the field itself. It is not a technology being introduced without local content. Farmers in the region have already identified a practical use for an available material. Scientific evaluation can now determine its effectiveness, limitations and economic feasibility.

Why this recommendation matters?

The recommendation is based on the practical characteristics of the material. A saree can be handled as a single sheet, potentially making application and removal easier. Its durability may allow repeated use. Re-use can extend the useful life of an otherwise discarded household textile. For small and marginal farmers, these characteristics may be particularly relevant because reducing expenditure and labour is often as important as improving technical efficiency. However, the recommendation must remain evidence-based. A covering material should noy be promoted solely because it appears convenient. Its effect on seed emergence and seedling development must also be understood.

Timely removal is critical

The effectiveness of any nursery covering material depends not only on the material but also on when it is removed. ICAR nursery guidance recognises paddy-straw covering as a means of protecting nursery seed and emphasises appropriate management of the cover seedlings emerge. Prolonged covering an restrict sunlight and result in weak, elongated seedlings. ICAR-NIR-Nursery Management. Therefore, whether the farmer uses straw or saree, the principle remains the same. Cover when protection is required and remove the cover when the emerging seedlings require adequate sunlight. If an old saree is used, it should preferably be clean and dry, sufficiently durable and free from materials that could adversely affect the nursery, it should also be removed carefully so that emerging seedlings are not disturbed.

From Indigenous practice to scientific validation

The saree-covering practice observed in Kannanur village provides an excellent opportunity for field-based research. A comparative study between paddy straw and reusable cloth could be conducted under similar nursery conditions. Seed emergence, germination, seedling vigour, seedling height, nursery moisture, temperature, coverage uniformity, labour requirement, application time, removal time, material cost, durability and number of possible reuses could be evaluated. A strategy such as this would help in verifying the effectiveness of practical gains made from the field. Indeed, the ICAR-IARI publication itself underscores the significance of scientific research in evaluating whether sarees could

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be used as replacements for other coverings available. Herein lies the role that agriculture science can play in enhancing indigenous knowledge without negating it.

Resource reuse as Farmer innovation

The saree-covering practice also reflects an important principle of sustainable agriculture: making better use of resource that are already available. The farmer does not necessarily need a new product to solve every field problem. An existing resource can sometimes be adapted to meet a new requirement. Paddy straw represents one form of resources utilisation, where a crop residue is used within the production system. The old saree represents one form of resource utilisation, where a crop residue is used within the production system. The old saree represents another, where a household material is given a second productive use in agriculture. Both approaches are rooted in resourcefulness. The difference is that one comes directly from the farm, while the other comes from the household.

RAWE: Learning Beyond the Classroom

Our experience at Kannanur village demonstrated the importance of experiential learning in agricultural education. In the classroom, we learn about nursery systems and covering materials. In the field, we see how farmers actually make decisions. We observe the materials they use, understand their reasons and recognise the practical constraints that influence their choices. Most importantly, field exposure teaches us to appreciate that farmers are not merely recipients of agricultural technologies. They are also innovators. The indigenous use of sarees as nursery covering material is a powerful example of this. A farmer identifies a locally available resources, adapts it to a field requirement and continues the practice based on practical experience. RAWE provides us with the opportunity to observe such innovations directly and connect them with scientific knowledge.

Conclusion

The use of paddy straw as a nursery covering material remains a practical and well- established practice among rice farmers. Its local availability, low cost, familiarity and ability to protect newly sown seed explain why farmers continue to depend on it. However, our RAWE field experience in Kannanur village, Chetpet Block, Tiruvannamalai district, revealed another indigenous possibility – the use of old sarees as temporary nursery covering materials, a practice followed by many paddy farmers in the region. The saree offers a different set of potential advantages: its continuous sheet form, ease of spreading and removal, potential for repeated use and productive reuse of household material. We therefore recommend not an immediate replacement of straw, but the scientific evaluation and documentation of indigenous saree- covering technique already practised by farmers. If future field studies that sarees provide adequate protection while offering advantages in handling, reusability, labour or cost, the practice could become useful locally adaptable option for paddy nursery management. This experience reminds us that agricultural innovation does not always come from outside he farming community. Sometimes, it is already present in the field. The farmer provides the innovation, the field provides the observation, and the science provides the validation. It is evident that, an old saree can become more than a piece of cloth, it can become a symbol of resourcefulness, indigenous knowledge and farmer-led innovation in agriculture.

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document indigenous farming practices in Kannanur village.

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Physiological Effects of Microplastics on Livestock Health and Productivity

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Farmed animals, including livestock and aquaculture species, are central to global food security, providing essential proteins, fats, and micronutrients (Liu *et al*., 2022). However, increasing plastic use and its environmental persistence have created an emerging challenge for agricultural and food systems. Plastics are widely used because of their durability, versatility, and low cost, yet only about 9% of the approximately 6.3 billion tonnes of plastic waste generated globally has been recycled (Alabi *et al*., 2019).

Microplastics (MPs; generally <5 mm) arise as primary particles or through fragmentation of larger plastics, while further degradation can generate nanoplastics (NPs; generally <100 nm) (Yee *et al*., 2021). Their small size, persistence, and mobility have resulted in widespread distribution across soil, freshwater, marine, and atmospheric environments, with transport facilitated by wind, runoff, and rivers (Fackelmann & Sommer, 2019; Chamas *et al*., 2020). Beyond their physical presence, MPs can interact with persistent organic pollutants, heavy metals, additives, and microorganisms, potentially modifying their environmental fate and biological effects (Campanale *et al*., 2020).

Of particular concern is their entry into biological systems and the food chain. MPs and NPs have been detected in biological samples, including human stool, demonstrating widespread exposure (Schwabl *et al*., 2019). Livestock may encounter these particles through contaminated feed, water, soil, and air, positioning farmed animals at the interface between environmental contamination, animal health, and food safety. Their potential transfer through animal-derived foods therefore places livestock within an important environment-animal-food-human continuum. Despite growing concern, major gaps remain regarding livestock exposure, biological effects, and food-chain transfer, highlighting the need to address microplastic pollution within a One Health framework (Muhammad *et al*., 2021).

2. Environmental Distribution and Exposure Pathways

Microplastics (MPs) are widely distributed across terrestrial, aquatic, and atmospheric environments and are transported by wind, water currents, and river flow (Wright & Kelly, 2017). They enter biological systems mainly through aquatic ingestion and contaminated water/feed, terrestrial contamination of soil and vegetation, and inhalation of airborne particles. These pathways facilitate entry into food webs and may promote trophic transfer and bioaccumulation (Prata *et al*., 2020).

3. Microplastics in Livestock: Sources and Significance

Livestock are exposed to MPs through contaminated feed and water, soil ingestion, inhalation, and agricultural practices such as plastic mulching, sewage-sludge application, and plastic-based feed storage (de Souza Machado *et al*., 2018). Their presence in animal-derived foods, including milk, meat, and eggs, raises concerns regarding food safety and human exposure (Toussaint *et al*., 2019). However, their effects on livestock gut health, metabolism, productivity, and welfare remain insufficiently understood.

4. Endocrine Disruption

MPs can act as carriers of endocrine-disrupting chemicals (EDCs), including bisphenols, phthalates, pesticides, persistent organic pollutants, and heavy metals. These co-contaminants can interfere with hormone synthesis, receptor signaling, steroidogenesis, and the hypothalamic-pituitary-gonadal axis, potentially affecting growth, metabolism, reproduction, and physiological homeostasis (Rochman *et al*., 2013; Jin *et al*., 2021).

5. Biological Effects of Microplastics and Nanoplastics on Farmed Animals

5.1 Effects on the Reproductive System

MPs and NPs may impair reproductive function through oxidative stress, inflammation, endocrine disruption, and cellular damage (Yang *et al*., 2023). In females, exposure has been associated with ovarian inflammation, impaired follicular development, altered oocyte quality, and hormonal disturbances (Liu *et al*., 2022). In males, MPs have been linked to reduced sperm quality, altered testosterone levels, testicular inflammation, and impaired spermatogenesis (Jin *et al*., 2021). NPs may additionally cross biological barriers, raising concerns regarding prenatal and developmental effects (Prüst *et al*., 2020). Long-term and transgenerational effects, including epigenetic alterations, have also been reported and warrant further investigation (Yan *et al*., 2024).

5.2 Nervous and Immune System Effects

MPs and NPs can induce neuroinflammation, oxidative stress, and neuronal injury, with smaller particles having greater potential to cross biological barriers (Segovia-Mendoza *et al*., 2020). They also modulate immune responses by altering cytokine production, phagocytic activity, and immune-cell function, potentially promoting chronic inflammation and impaired host defense (Liu *et al*., 2022).

5.3 Digestive System and Metabolic Effects

Ingestion of MPs/NPs can compromise intestinal integrity, mucus production, gut permeability, and microbiota composition, promoting inflammation and systemic exposure (Toto *et al*., 2022; Li *et al*., 2020). Reported effects include altered lipid, bile acid, amino acid, and short-chain fatty acid metabolism, along with hepatic oxidative stress and lipid accumulation (Okamura *et al*., 2023). Mitochondrial dysfunction and increased ROS may further disrupt cellular energy metabolism (Lin *et al*., 2022).

5.4 Respiratory System

Inhaled MPs/NPs can deposit throughout the respiratory tract, with smaller particles reaching deeper lung regions and potentially entering systemic circulation. Their deposition can activate macrophages, dendritic cells, and neutrophils, leading to oxidative stress, inflammation, and altered immune responses (Yang *et al*., 2023).

5.5 Food Safety and Human Health

MPs and NPs may enter the human food chain through contaminated animal-derived products such as meat and milk (Zhou *et al*., 2022). Following ingestion, smaller particles may cross the intestinal barrier and reach systemic organs, where they have been associated with oxidative stress, immune dysregulation, and microbiota alterations (López de las Hazas *et al*., 2022). Their ability to transport additives, heavy metals, and persistent organic pollutants may further increase potential health risks (Teuten *et al*., 2009).

6. Strategies to Reduce Microplastic Burden in Farmed Animals

Agriculture is a major consumer of plastics, making it an important target for reducing microplastic (MP) and nanoplastic (NP) contamination (FAO, 2023). Key measures include source reduction, improved waste management, and sustainable alternatives (Hofmann *et al*., 2023). Plastic-intensive practices

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such as silage wrapping and conventional mulch films should be minimized, with greater use of reusable, biodegradable, or natural materials such as jute, coir, paper, and straw. Bioplastics including PHA, PLA, PBAT, and TPS may offer alternatives, although their degradation depends on environmental conditions. Oxo-degradable plastics should be avoided because they fragment rather than fully mineralize (Wei *et al*., 2020). Efficient collection, recycling, and safe disposal of agricultural plastics are also essential to prevent environmental leakage (NTNU, 2024).

6.1 Technological Solutions

Advanced wastewater-treatment systems, including membrane bioreactors and nanofiltration, can reduce MP release into aquatic environments (Prüst *et al*., 2020). At the material level, biodegradable polymers and reduced use of hazardous additives can further limit persistence and toxicity (NTNU, 2024). However, technological measures should complement, rather than replace, source prevention and improved waste management.

6.2 Behavioral and Societal Interventions

Reducing single-use plastics, promoting responsible consumption and disposal, and strengthening recycling awareness are important for limiting plastic waste (Sun *et al*., 2021). Public education and community initiatives can further support sustainable practices and increase awareness of potential livestock-to-human food-chain exposure.

6.3 Policy Recommendations

Effective control requires coordinated action at global, national, and local levels. International frameworks should promote plastic reduction and safer alternatives, while Extended Producer Responsibility (EPR) can improve accountability across the plastic lifecycle. At the local and agricultural levels, stronger waste-management infrastructure, reduced plastic use, and adoption of biodegradable alternatives are essential to limit contamination of soil, water, and livestock systems (FAO, 2023).

7. Recommendations and Conclusion

Microplastic pollution represents an emerging One Health concern with potential implications for ecosystem integrity, livestock health, food safety, and human health. Future research should prioritize standardized methods for MP/NP detection and quantification, establishment of safe exposure limits in livestock feed and animal-derived foods, and investigation of long-term, reproductive, transgenerational, and combined effects with other contaminants. Development of safer bio-based polymers, improved waste management, and advanced monitoring approaches using machine learning, remote sensing, and predictive modelling could strengthen risk assessment. Given the large number of potentially hazardous chemicals associated with plastics, safer material design and stronger regulatory oversight are also essential (NTNU, 2024).

Effective management requires a shift from reactive remediation toward prevention and source reduction, supported by reduction in plastic use, circular-economy practices, safer materials, Extended Producer Responsibility, industry accountability, and public awareness. Addressing the challenge requires an interdisciplinary One Health approach integrating environmental science, toxicology, materials science, animal health, policy, and public health. Coordinated action across these sectors will be critical to reduce microplastic exposure, protect animal welfare and food security, and minimize potential risks to human health.

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AIML: AI, Big Data, and Automation: Driving the Future of Smart Agriculture

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Agriculture is experiencing a profound technological transformation through the integration of Artificial Intelligence (AI), Machine Learning (ML), Big Data, and automation. These advanced digital technologies are reshaping traditional farming practices into smart agriculture systems, where data-driven decision-making enhances productivity, improves resource-use efficiency, and promotes environmental sustainability. With the global population projected to reach nearly 10 billion by 2050, the need to increase agricultural production while conserving limited natural resources has become increasingly critical. AI-enabled technologies support farmers by providing timely insights, optimizing the use of inputs, and improving overall farm profitability (FAO, 2022).

In contrast to conventional farming, which primarily depends on farmers' experience and generalized advisory recommendations, smart agriculture relies on real-time data generated from satellites, drones, sensors, weather stations, and agricultural machinery. AI processes and interprets these large volumes of data to deliver precise recommendations for irrigation scheduling, nutrient management, pest and disease control, and harvest planning. As a result, farmers can achieve higher crop productivity, reduce input wastage, and minimize adverse environmental impacts through more efficient and informed farm management practices (Wolfert et al., 2017).

Artificial intelligence: The brain behind smart farming

Artificial Intelligence (AI) refers to computer systems that can perform tasks typically associated with human intelligence, such as learning from data, reasoning, identifying patterns, and making informed decisions. In agriculture, AI acts as an intelligent digital advisor by analyzing large volumes of agricultural data and generating insights that support efficient and accurate farm management decisions.

AI is increasingly being adopted across different stages of the agricultural value chain. Farmers use AI-enabled mobile applications to identify crop diseases by capturing images of affected leaves, allowing rapid and accurate diagnosis. AI systems integrate weather forecasts, soil information, and crop growth data to recommend the optimal timing for irrigation, fertilizer application, and other crop management operations. In addition, AI supports governments, agricultural agencies, and agribusiness organizations in forecasting crop production, assessing food availability, and improving supply chain planning and management (Javaid et al., 2023).The combination of AI with drones and satellite-based remote sensing has significantly improved crop monitoring and field surveillance. Rather than relying solely on manual field inspections, farmers can detect nutrient deficiencies, pest infestations, disease outbreaks, and water stress at an early stage, often before visible symptoms appear. This enables timely intervention, reduces

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potential crop losses, and enhances overall agricultural productivity.

AI also plays a crucial role in livestock management. Wearable sensors and smart monitoring devices continuously track animal movement, feeding patterns, body temperature, reproductive status, and milk production. AI algorithms analyze these data streams to identify unusual behavioural or physiological changes that may indicate disease or health disorders, enabling early treatment, improving animal welfare, and reducing mortality rates.

Machine learning: learning from agricultural data

Machine Learning (ML) is a specialized field of Artificial Intelligence that enables computer systems to learn from data and improve their performance without being explicitly programmed for every task. Rather than relying on predefined rules, ML algorithms analyze historical and real-time agricultural data to identify patterns, generate predictions, and continuously enhance their accuracy as additional data become available (Liakos et al., 2018).A major application of ML in agriculture is crop yield prediction. By examining factors such as weather patterns, soil characteristics, irrigation practices, fertilizer application, and historical yield records, ML models can forecast future crop production with a high degree of accuracy. These predictions assist farmers in planning crop management practices while also supporting insurance providers, agribusinesses, and policymakers in production forecasting, risk assessment, and market planning.

Deep learning, an advanced subset of ML, has substantially enhanced image-based crop diagnosis and disease detection. Convolutional Neural Networks (CNNs) are capable of identifying diseases such as rice blast, tomato leaf curl, wheat rust, and maize leaf blight from digital images with remarkable precision, enabling rapid and reliable disease diagnosis (Kamilaris & Prenafeta-Boldú, 2018).

ML is also playing an important role in precision weed and pest management. Computer vision technologies can differentiate crops from weeds and direct robotic weeders or precision spraying systems, thereby reducing herbicide use and minimizing environmental impacts. In addition, predictive ML models integrate weather information, crop growth stages, and historical pest incidence data to forecast potential pest outbreaks, allowing farmers to implement timely preventive measures rather than relying solely on reactive pest control strategies.

Big data: the new agricultural resource

Contemporary agriculture generates massive volumes of data from a wide range of sources, including weather stations, satellites, drones, Internet of Things (IoT) devices, mobile applications, farm machinery, and agricultural market information systems. These large and complex datasets are collectively known as Big Data.

Big Data is commonly defined by five key characteristics: Volume, Velocity, Variety, Veracity, and Value. Through advanced data analytics, these diverse datasets can be transformed into actionable insights that enhance precision farming, strengthen climate adaptation strategies, and support evidence-based agricultural planning and policymaking (Wolfert et al., 2017).One of the most significant contributions of Big Data is its ability to enable site-specific farm management. By detecting spatial variability within agricultural fields, farmers can apply water, fertilizers, and other inputs according to the specific needs of different field zones rather than using uniform application rates across the entire farm. This targeted approach improves input-use efficiency, lowers production costs, and reduces environmental pollution.

Big Data is also widely used by governments, research institutions, and agricultural organizations for large-scale agricultural monitoring and planning.

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It supports the assessment of crop acreage, forecasting of agricultural production, identification of drought-prone areas, and formulation of agricultural development policies. The integration of remote sensing technologies with Big Data analytics has become a critical component of climate-smart agriculture, enabling more resilient and sustainable farming systems (Wolfert et al., 2017).

Automation: farming beyond manual labour

Automation involves the use of intelligent machinery, robotic systems, and digital technologies to perform agricultural operations with minimal human involvement. The growing shortage of agricultural labour, increasing labour costs, and the demand for greater operational precision have significantly accelerated the adoption of automation technologies in agriculture across the world (FAO, 2022).

Modern farms are increasingly adopting autonomous tractors equipped with GPS-guided navigation systems capable of carrying out land preparation, sowing, and harvesting operations with limited operator intervention. Similarly, automated irrigation systems use soil moisture sensors and weather forecast data to deliver water precisely when crops require it, improving water-use efficiency and crop performance.Agricultural drones have emerged as important tools for a wide range of farming activities, including crop monitoring, pesticide application, fertilizer spraying, and yield estimation. Compared with conventional spraying methods, drone-based applications improve precision, reduce chemical consumption, and minimize workers' exposure to hazardous pesticides.

Robotic harvesting technologies represent another major advancement in agricultural automation. Integrated with computer vision and AI systems, these machines can identify ripe fruits and vegetables and harvest them with precision and care, thereby reducing labour dependence and minimizing post-harvest losses.Automation has also transformed greenhouse cultivation, where intelligent environmental control systems continuously regulate temperature, humidity, light intensity, and nutrient supply. These automated systems maintain optimal growing conditions throughout the year, improving productivity, resource efficiency, and crop quality (FAO, 2022).

Integration of AI, ML, Big Data, and automation

The greatest potential of digital agriculture lies in the seamless integration of Artificial Intelligence (AI), Machine Learning (ML), Big Data, and automation into a unified intelligent farming system. Rather than functioning independently, these technologies work together to create a connected agricultural ecosystem that supports precise, efficient, and data-driven farm management.

Within this integrated system, IoT sensors continuously collect real-time information on soil moisture, nutrient status, temperature, weather conditions, and crop growth. Big Data platforms store, organize, and process these large and diverse datasets, while ML algorithms analyze the information to identify patterns, forecast future conditions, and generate predictive insights. AI then transforms these predictions into actionable farm management recommendations, and automated machinery carries out the recommended operations with minimal human intervention.

For instance, when soil moisture sensors detect water stress in a field, ML models can predict future moisture availability, AI determines the optimal irrigation requirement, and an automated irrigation system delivers the precise amount of water needed. Such integration enhances operational efficiency, improves resource-use efficiency, reduces input wastage, and ultimately increases agricultural productivity and farm profitability.

Benefits for Farmers

The adoption of AI, ML, Big Data, and automation offers numerous advantages:

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- Higher crop productivity and improved yields
- Efficient use of water, fertilizers, and pesticides
- Early detection of pests and diseases
- Reduced labour dependency and production costs
- Accurate weather and yield forecasting
- Improved market intelligence and price prediction
- Enhanced climate resilience
- Better environmental sustainability
- Reduced greenhouse gas emissions
- Improved food security

Myths vs Facts: AI, Machine Learning, Big Data, and Automation in Agriculture

Myth	Fact
AI will replace farmers.	AI is designed to support farmers by providing data-driven recommendations and improving decision-making. Human expertise remains essential for interpreting local conditions and managing farms.
AI is only for large commercial farms.	Affordable AI-enabled mobile apps, digital advisory platforms, drones-on-hire, and sensor-based services are increasingly making smart farming accessible to small and marginal farmers.
Automation means completely driverless farms.	Most agricultural automation today assists farmers by performing repetitive or precision tasks, while farmers continue to supervise and make key management decisions.
Big Data is useful only for researchers and governments.	Big Data benefits farmers by providing localized weather forecasts, pest alerts, market intelligence, irrigation schedules, and personalized crop management recommendations.
Machine Learning always provides perfect predictions.	ML predictions depend on the quality, quantity, and relevance of data. Poor or incomplete data can reduce prediction accuracy.
AI can eliminate all crop diseases and pests.	AI cannot eliminate pests or diseases, but it can detect them early, predict outbreaks, and recommend timely management practices to minimize losses.
Digital agriculture is too expensive for ordinary farmers.	While some advanced technologies require substantial investment, many AI-based advisory services, mobile applications, and government-supported digital tools are affordable or free.
More data automatically leads to better decisions.	Data alone has limited value. Meaningful insights are generated only when high-quality data are analyzed using AI and Big Data analytics.
Automation increases environmental damage.	Precision automation often reduces excessive use of water, fertilizers, and pesticides, leading to lower environmental pollution and more sustainable farming.
AI can replace agricultural	AI complements extension services by providing instant information and personalized

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extension workers.	recommendations, but extension professionals remain essential for field demonstrations, farmer training, and addressing local socio-economic issues.
AI works effectively even without internet connectivity.	Many cloud-based AI applications require internet access; however, emerging technologies such as Edge AI allow certain AI functions to operate offline on smartphones and farm devices.
Robots can perform every farming activity.	Agricultural robots are highly efficient for specific tasks such as weeding, spraying, harvesting, and monitoring, but many complex farm operations still require human judgment and adaptability.

Challenges to adoption

Despite their significant potential, the adoption of AI, ML, Big Data, and automation in agriculture faces several constraints, particularly in developing countries. The high initial cost of advanced technologies often limits their accessibility for many farmers. In addition, inadequate internet connectivity, insufficient digital infrastructure, fragmented landholdings, and low levels of digital literacy continue to hinder widespread adoption. Concerns related to data privacy, interoperability among digital platforms, and the limited availability of skilled technical professionals further complicate the effective implementation of these technologies.

Addressing these challenges requires coordinated efforts involving governments, research institutions, private-sector organizations, and extension agencies. Public-private partnerships, enabling policy frameworks, affordable digital solutions, and strong agricultural extension systems are essential to ensure that the benefits of digital agriculture reach both large-scale commercial farmers and smallholder farming communities (Klerkx et al., 2019).

Future prospects

Agriculture is expected to become increasingly intelligent, automated, and sustainable in the coming years. Emerging technologies such as Generative AI, Digital Twins, Edge AI, Explainable AI, Blockchain, Autonomous Robotics, and the Internet of Agricultural Things (IoAT) are likely to transform agricultural production systems and farm management practices.

Countries including India are actively advancing digital agriculture through initiatives such as the Digital Agriculture Mission, AgriStack, and AI-based agricultural advisory services. As these technologies become more affordable, scalable, and accessible, they are expected to enhance farm productivity, improve profitability, strengthen climate resilience, and support more sustainable agricultural development.

Conclusion

Artificial Intelligence, Machine Learning, Big Data, and automation are transforming agriculture from a labour-intensive and experience-dependent activity into a knowledge-driven and technology-enabled sector. These technologies enable farmers to monitor crops in real time, anticipate production risks, optimize the use of water and agricultural inputs, and automate essential farming operations. Although barriers related to affordability, infrastructure, and digital literacy remain significant, continued investments in research, supportive public policies, digital infrastructure, and agricultural extension services will accelerate the adoption of smart farming technologies. The integration of these digital innovations is crucial for enhancing food security, improving environmental sustainability, and building resilient agricultural systems capable of meeting the needs of a rapidly growing global population.

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Fish Surimi: Process and Value-Added Products

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Surimi technology is an effective method for utilizing underutilized fish species and producing value-added seafood products. Surimi is prepared by deboning, mincing, washing, refining, and dewatering fish muscle to concentrate myofibrillar proteins responsible for gel formation. Washing removes sarcoplasmic proteins, pigments, lipids, blood, and proteolytic enzymes. Cryoprotectants preserve protein functionality during frozen storage. Traditionally, Alaska pollock is widely used, but alternative species and bycatch are increasingly explored. Surimi serves as an intermediate product for fish balls, kamaboko, and seafood analogues.

Introduction

Due to declining marine catch and rising consumer demand for fish products, it has become increasingly important to fully exploit fish landings, especially underutilised fish species, as human food. Although there are many ways to add value to fish, surimi technology has been identified as one of the most effective ways to use fish at a minimal cost. A common culinary item in East Asian cuisines, surimi can be found in a variety of sizes and shapes, from fish balls to different types of seafood imitations, such as crab sticks. Fish meat that has been deboned, minced, and cleaned is used to make surimi (Gopakumar et al., 1992).

Highly processed seafood products known as surimi are created by removing soluble proteins, lipids, colours, and odorous chemicals from fish flesh. These products can then be frozen by adding cryoprotectants (CP). In reality, it should be considered an intermediate product as, when thawed, it serves as the foundation for traditional Japanese products like "kamaboko," which are generally referred to as "neriseihin," through a variety of heating techniques like steaming, frying, and broiling and a variety of more recent products such as shellfish analogues or crab sticks (Hall, 2011).

Fish Muscle Protein

Sarcoplasmic proteins are water-soluble and physiologically active molecules (enzymes and oxygen carriers), they might cause instability when they are liberated from certain cell structures by disruptive procedures like filleting, mincing, or other processing unit operations. They don't help with gel formation, and in fact, the proteases can reduce the capacity to gel by breaking down the myofibrillar proteins. The primary goal of the surimi process is to eliminate the sarcoplasmic proteins, which make up 18–20% of all muscle protein. The main goal of the surimi process is to remove the sarcoplasmic proteins, which make up 18–20% of all muscle protein. Myosin, actin, tropomyosin, and troponin are the myofibrillar proteins that make up the majority of muscle protein (65–80% of total muscle protein). Because these proteins can form a gel when heated, they contribute to the texture of both natural fish flesh and items made from surimi (Yin and Park, 2023).

The other main goal of the surimi process is the recovery of these concentrated proteins and their preservation after freezing. The stroma and connective tissue proteins, which make up only 3–5% of the total muscle protein in fish (unlike terrestrial animals) and contain collagen and elastin,

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are the most durable proteins. They are not usually totally eliminated throughout the surimi process; instead, they become "neutral" components in the finished product after being dissolved by the heating process (Gopakumar et al., 1992).

Surimi Processing

1. **Raw Material:** The quality of the raw materials is essential while making surimi. High-quality raw materials yield the best gel character and bland colour since there is less autolysis of native proteins and less contamination with blood and intestinal residues (Fig. 1).
2. **Pre- processing:** All the conventional pre-processing operations take place (heading, gutting, skinning, filleting and washing), and then this material is put through the deboner/separator for further separation of components of the original fish. By these means, the overall yield of the process might be only 18–36% of the original and so the recovery and use of the process wastes is essential (Fig. 1).
3. **Washing process:** It is at the centre of the surimi process, giving rise to the original product concept by removal of more components of the raw material: the water- soluble non- gel-forming proteins, proteolytic enzymes, pigments and blood, and lipids and lipid oxidation promoting haem compounds (Fig. 1).
4. **The refiner/strainer and dehydrator:** These stages are all designed to remove fine bones and skin and then water from the proteins to give the best gel- forming capability (Fig. 1).
5. **Addition of CP**: It was not a part of the traditional process but important for the industrial process where frozen storage has made large- scale production feasible. The traditional CPs were sucrose (4%), sorbitol (4%) and polyphosphates (0.3%) although a wider range is used today (Fig. 1).

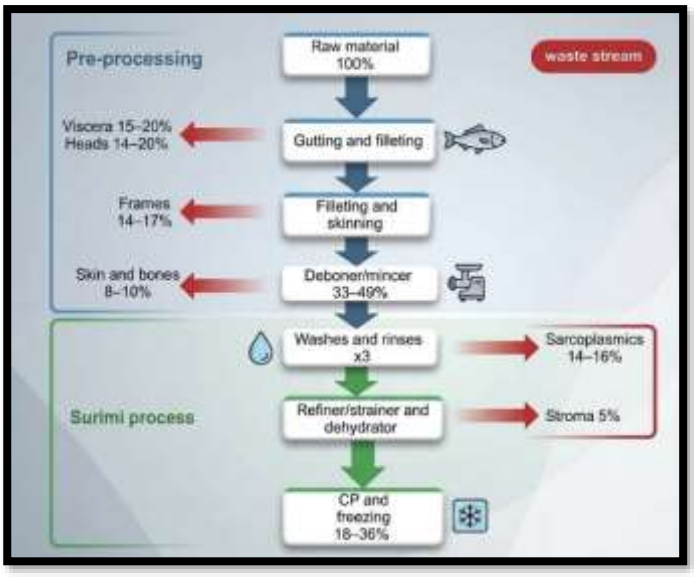

Fig. 1

Species used for surimi processing

Lean white fish is used for a traditional surimi because it is easier to produce a bland colour and has a bland taste because it has less lipids that need to be eliminated. Numerous alternative species have been tested due to the growing pressure on Alaska pollock (Theragra chalcogramma), the traditional species used for surimi in Japan. The variety of species studied has expanded since the invention of the mechanical flesh-bone separator, which made it possible to employ additional raw materials from small fish or bycatch (Shitole et al., 2014).

Products of surimi

Kamaboko: Usually shaped like a loaf, kamaboko are steamed, then sliced and served cold with dipping sauces or added to hot soups and chikama, a cheese-topped snack. Certain shapes have historic patterns of colour that represent regional manufacture.

Fig. 2

Eaten raw and frequently in salads, crab sticks are a type of kamaboko (kanikama) flavoured with crab, food colouring, and egg white. Eomuk or odeng, a

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street dish boiled in broth, is a South Korean variation of kamaboko (Fig. 2).

1. Hanpen: It is a white, square-shaped surimi product with regional variants that can be fried, broiled, or eaten with soup (Fig. 3).

2.Chikuwa: After the surimi is wrapped around a skewer, it is steamed or broiled to create chikuwa, a tube-shaped product with added salt, sugar, starch, and egg white. In Japan, chikuwa pieces that have been sliced from the cooked product are a common snack (Fig. 4).

3.Fish balls: In Asia, fish balls are widely consumed and prepared in a variety of regional styles, sometimes using surimi (Fig. 5).

Fig. 3, Fig. 4, Fig. 5

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The silent vine of virudhunagar: Rediscovering athalakkai (*momordica cymbalaria* hook.f.)-An underutilized vegetable crop

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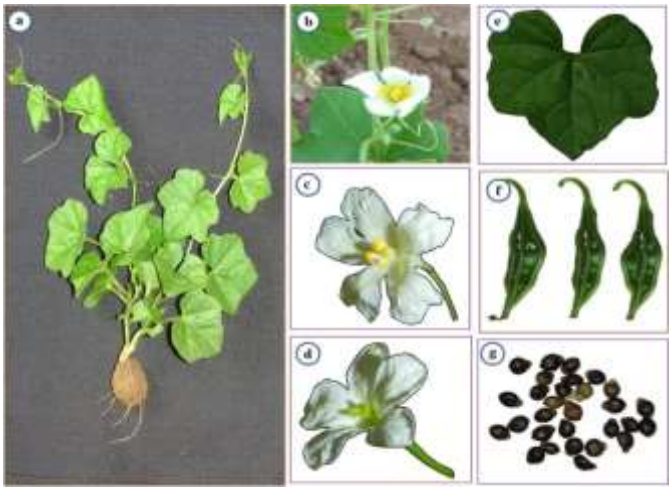
In the dry scrublands and field bunds of Virudhunagar district, Tamil Nadu, a quiet vine emerges every monsoon. Farmers often overlook this slender vine because of its small lobed leaves and pale yellow flowers, mistaking it for a common weed. Beneath the soil, however, lies a remarkable perennial tuber that can remain dormant for decades. With the arrival of the rainy season, it sprouts naturally, producing fresh vines, flowers, and fruits without being replanted. This unique plant is Athalakkai, scientifically known as *Momordica cymbalaria* Hook. f., a wild relative of bitter gourd (*Momordica charantia L.*) and one of India's most neglected underutilized vegetable crops.

Athalakkai belongs to the family **Cucurbitaceae** and is known by different vernacular names across South India, including **Kasarakayee in Andhra Pradesh, Karchikai in Karnataka, Kadavanchi in Maharashtra, and Athalakkai** in **Tamil Nadu**. In Virudhunagar district, it has traditionally been collected from the wild rather than cultivated as a commercial crop. The small, ridged, orange-red fruits are commonly harvested during the season and prepared as curries or fried dishes. The tubers and leaves are also valued in traditional medicine for treating ailments such as diarrhoea, skin disorders, ulcers, and liver-related problems.



Despite its rich nutritional and medicinal value, Athalakkai remains largely neglected in mainstream agriculture. The absence of improved varieties, poor seed germination due to hard seed coat dormancy, and limited scientific awareness have restricted its cultivation. However, its resilience to harsh environmental conditions, nutritional richness, and medicinal potential make it a promising crop for future research, conservation, and sustainable cultivation. Promoting Athalakkai can contribute to nutritional security, biodiversity conservation, and climate-resilient agriculture in dryland regions of India.

Propagation Techniques of Athalakkai

1.Vegetative Propagation (Tuber-based)

- The perennial woody tuber is the main organ of survival and propagation; the crop is propagated through tuber setts almost exclusively in traditional practice.
- Some sources note the crop duration runs roughly June–September in a growing cycle,

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with the tuber persisting dormant thereafter and re-sprouting the next season.

- Tubers are reported to remain viable in soil for extended periods (cited up to ~30 years in some literature), but multiplication rate via this method is inherently slow

2.Seed Propagation

- Seeds are hard-coated, and natural germination is poor and erratic; seeds are described as largely dormant under normal conditions.
- Comparative dormancy-breaking trials have found mechanical scarification (sandpapering or nicking the seed coat) more effective than chemical treatments (H_2SO_4, GA_3) or hot-water soaking.
- Even after treatment, germination remains modest (roughly 10–20%).

3.In Vitro propagation (Tissue Culture) :

- Developed to address the slow multiplication rate of tuber and seed methods, particularly for germplasm conservation.
- Explants used include seed, root-tuber, leaf, internode, and fruit tissue, cultured on MS (Murashige and Skoog) medium.
- Callus induction has been achieved using 2,4-D (3 mg/L) combined with BAP (0.2 mg/L); crude protein has also been extracted directly from callus tissue for biochemical/antidiabetic assays (α-amylase inhibition studies), linking tissue-culture work k directly to the pharmacological research on Mcy protein.
- Direct organogenesis from axillary buds and multiple-shoot regeneration from nodal/leaf explants (using BA/Kn with IAA, NAA, or 2,4-D) have also been reported, with stem-derived explants generally outperforming leaf explants.

Nutritional and Medicinal Value of Athalakkai *(Momordica cymbalaria)* :

1.Nutritional composition of athalakkai (*Momordica cymbalaria* hook .f.)fruit (per 100 g edible portion):

Nutrient	**Content (per 100 g)**
Potassium	**505.92 mg**
Calcium	**73.57 mg**
Sodium	**41.58 mg**
Zinc	**2.76 mg**
Iron	**1.71 mg**
Ascorbic acid(vit c)	**299-300 mg**
Total carotenoids	**2.81 mg**

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Lycopene	**1.86 mg**
Crude protein	**Present**
Dietary fibre	**High**
Carbohydrates	**Present**
Unsaturated fatty acids	**Palmitic, oleic, stearic acids**

2.Medicinal Value

Traditional Uses

- Used for the treatment of skin disorder.
- Used t manage rheumatism and ulcers.
- Used to treat diarrhoea.
- Traditionally used for spleen and liver disorder.
- Reported in folk medicine as an abortifacient.

Culinary Uses:

- Prepared in southern India (Tamil Nadu, Karnataka, Andhra Pradesh) as stir-fries (*poriyal*), kuzhambu, and pickles. It has a bitter taste similar to bitter gourd (*karela*) but is smaller and crisper

Validated Pharmacological Activities

- Hypolipidemic: Reduces blood lipid levels along with glucose-lowering effects.
- Hepatoprotective and Nephroprotective: Improves liver and kidney function markers in diabetic animal models.
- Cardioprotective: Demonstrates protective effects on cardiac function.
- Antioxidant: Attributed to the presence of phenolic compounds, flavonoids, and tannins.

Conclusion

Athalakkai (*Momordica cymbalaria* Hook. f.) exemplifies the untapped potential of India's underutilized vegetable crops. It combines a nutrient-rich fruit containing high levels of vitamin C, essential minerals, and dietary fibre with well-documented medicinal properties, including antidiabetic, hypolipidemic, hepatoprotective, nephroprotective, and antioxidant activities. Despite these promising attributes, the species remains largely confined to wild populations in Virudhunagar district due to hard seed coat dormancy, slow tuber-based propagation, and the absence of improved varieties and standardized cultivation practices. However, recent advances in propagation techniques, including mechanical seed scarification and tissue culture-based micropropagation, together with the documented genetic variability among local accessions, offer promising opportunities for its domestication and commercial cultivation. With continued efforts in germplasm conservation, crop improvement, agronomic standardization, and pharmacological validation, Athalakkai has the potential to become a valuable climate-resilient vegetable crop, contributing to nutritional security, biodiversity conservation, and sustainable agriculture in India.

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Minor Vegetables: "Hidden Treasures" of Indian Horticulture

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As we know India possesses a rich diversity of vegetable crops, including a large number of minors, underutilized and traditional vegetables. Although these vegetables are generally cultivated on a smaller scale than major vegetables such as tomato, potato and brinjal, they have considerable nutritional, medicinal, ecological and economic importance. *Nutritional deficiencies of iron, vitamin A, vitamin C, folate, calcium and other micronutrients can result in disorders such as anemia, impaired immunity, poor bone development, scurvy and vision-related problems.* Minor vegetables can contribute significantly to preventing such deficiencies because many of them are rich sources of vitamins, minerals, dietary fiber, antioxidants and other bioactive compounds. *Vegetables such as moringa, amaranth, Basella, Colocasia, cluster bean, bitter gourd etc.* have traditionally been consumed in different parts of India. Their inclusion in daily diets can improve dietary diversity and nutritional security.

Introduction

Minor vegetables are those vegetable crops that are cultivated and consumed on a relatively limited scale compared with major commercial vegetables. They may be regionally important, traditionally grown or adapted to specific agro-climatic conditions. Examples include moringa, amaranth, Basella, agathi, kachnar, Colocasia, elephant foot yam, cluster bean, ivy gourd, pointed gourd and several other indigenous vegetables.

India has enormous diversity in minor and underutilized vegetables because of its varied climate, soil conditions and rich traditional knowledge. Many of these crops can grow successfully under low-input conditions and are suitable for small and marginal farmers, kitchen gardens and nutrition garden.

On basis on plants part used-

Plant parts	Crops
Leaf	Amaranthus, Basella, kulfa, bathua
Fruiting	Ivy gourd, spine, Indian round gourd, Kachri
Root	Turnip, taro, carrot, radish
Stem	Lotus stem, celery, bamboo shoot
Tuber	Elephant foot yam, Colocasia, Chinese potato
Legumin ous	Cluster bean, cowpea, winged bean, jack bean
Perennial	Drumstick, curry leaf

Important Minor vegetable crops:

a) **Amaranthus:** *Amaranthus tricolor,* **Family-** Amaranthaceae

- **Origin-** *India & Tropical America.*
- **Morphological characters:** Annual leaf, soft succulent stem, Broad green / Red leaves. Small flower arranged in spikes, Tiny black seeds.
- **Climate:** warm & humid climate [20-35°c), 6-7.5 pH [soil).
- **Nutritional value:** Fe, Ca, Vit A, C, Protein.
- **Uses:** Leafy veg, Soup, Curry, Salad.

b) **Basella (Malabar Spinach):** *Basella alba*

- **family-** basellaceae

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- **Morphology:** Perennial climbing wine, thick fleshy leaves,
- Succulent stem, purple / white berries.
- **Nutrition's:** Fe, Ca

Spine gourd: *Momordica diocia*

- **family-** Cucurbitaceae
- **Morphology:** perennial climber, spiny oval fruits
- Separate female and male plants.

c) Ivy gourd: *coccinia grandis*

- **family-** Cucurbitaceae
- **Morphology:** perennial climber, small elongated fruits
- White flowers
- Uses- veg, pickle, traditional medicine

d) **Drumstick:** *Moringa oleifera*

- **Family**→ Moringaceae
- **Morphology:** Small perennial tree, compound leaves,
- long pods, white flower.
- Nutritional value: Ca, Fe, vit A, Protein.
- Imp: veg, medical plant, Nutraceutical Crop

e) **Cluster bean:** *Cyamopsis tetragonaloba*

- **family -**Fabaceae
- **Imp:** Tender pods consumed as veg.
- Source of guar gum, Drought tolerant

f) **Elephant Foot Yam:** *Amorphophallus paroniifalious,*

- **Family**→ Araceae
- **morphology:** Underground corm, large divided leaf,
- possess thick pseudo stem
- **Uses:** Curry, Chips, Processing

h) **Colo cassia (Taro):** *Colocasia esculenta*

- **Family-** Araceae
- **Imp:** Edible corms, leaves also consumed, Rich in Carbo.
- Also contains dietary fibre and minerals
- Widely used in curries, fried preparation and traditional Dishes.

Other Important minor vegetables and their nutritional significance:

Minor vegetable	Edible part	Major nutrients/ comp.	Major health significance
Agathi	Flowers, leaves	Ca, Fe, vitamins	Nutritious leafy veg's
Kachnar	Flower buds, flowers	Fibre, antioxidants	Medicinal uses
Bitter gourd	Immature pods	Vit, fibre, bioactive comp	Metabolic health improves
Tinda	Immature pods	Water, fibre, minerals	Nutritious vegetable
Indian beans/ Sem	Tender pods, seeds	Protein, fibre, minerals	Nutritional rich
Kohlrabi/ganth gobhi	Swollen stem	Vit. C, fibre, minerals	Antioxidant rich
Mustard greens	Leaves	Carotenoids, vit C, Ca	Micronutrient intake
Bathua	Leaves	Fe, Ca, Carotenoids, fibre	Nutritious leafy veg's
Purslane/kulfa	Tender shoots	Omega-3 fatty acids, antioxidants, minerals	Antioxidant-rich leafy Vegetable

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Malabar spinach	Leaves, shoots	Vitamins, minerals, fibre	Nutritious leafy veg's

Future scope:

The future of minor vegetables lies in their wider promotion, scientific improvement and better utilization. Greater attention is needed towards the development of improved and high-yielding varieties, efficient production practices and quality planting material. Processing and value addition can create new products and improve market opportunities for farmers. Organic and natural farming systems may further increase their appeal, while their adaptability to diverse environments makes them promising crops for climate-resilient horticulture. With suitable research, market support and consumer awareness, minor vegetables can gradually move from local consumption towards wider commercial use and value-added products.

Conclusion:

Minor vegetables may occupy a smaller place in commercial vegetable production, but their importance should not be underestimated. They offer nutritional diversity, support traditional food systems and provide opportunities for crop diversification and additional income. Many of these crops are also adapted to local growing conditions and can be useful in sustainable and climate-resilient production systems. Promoting their cultivation, consumption, processing and marketing, along with proper research and conservation of their genetic diversity, can help bring these lesser-known vegetables into the mainstream of Indian horticulture.

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More Crop Per Drop: The Benefits of Micro-Irrigation in Spice Crops

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India is facing an increasing water crisis and spice crops are the backbone of the country's agricultural exports. Conventional flood irrigation is exceptionally inefficient, wasting water through runoff, evaporation and deep percolation while failing to meet the precise moisture demands of crops such as chilli, cumin, garlic, turmeric, cardamom and black pepper. Micro-irrigation technologies particularly drip irrigation, micro-sprinkler systems and subsurface drip irrigation (SDI) achieve water-use efficiencies of 90 to 98 per cent delivering water directly to the root zone with minimal loss. When integrated with fertigation, micro-irrigation becomes a dual tool for water and nutrient management, enabling stage-specific delivery of inputs.

1. Introduction

Water is the lifeblood of agriculture and agriculture accounts for nearly 72 per cent of all freshwater withdrawals in the country and demand is projected to exceed supply dramatically with rising to an estimated 1,498 billion cubic metres by 2030 against a likely supply of only 744 billion cubic metres (NITI Aayog, 2018). For spice-growing states such as Rajasthan, Gujarat, Andhra Pradesh and Karnataka which together contribute the bulk of India's spice production the situation is even more persistent. These regions are already classified in the high to extremely high water stressed zones by the World Resources Institute (2020). Spice crops are not tolerant of uncertainty when it comes to water. Chilli needs 1,000 to 1,500 mm of moisture per season, black pepper demands 2,000 to 3,000 mm, cumin is acutely sensitive to any moisture deficit during seed filling and garlic responds directly to soil moisture levels in terms of both bulb size and quality. Yet across most spice growing regions, the dominant method of irrigation remains flood or furrow irrigation system that is easy to manage but deeply wasteful, with field level efficiency rarely exceeding 40 per cent. Micro-irrigation encompassing drip irrigation, micro-sprinkler systems, bubbler systems and subsurface drip irrigation represents the technological response to this challenge. By delivering water drop by drop directly to the root zone, micro-irrigation achieves efficiencies of 90 to 98 per cent. When combined with fertigation, it transforms a simple water pipe into a precision nutrition system. The philosophy guiding modern irrigation science "More Crop Per Drop" finds its most complete expression in micro-irrigation applied to high value crops like spices.

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2. Water challenge in spice crop cultivation

Spice crops are particularly exposed to moisture stress because their marketable yield and quality parameters like capsaicin content in chilli, essential oil concentration in cumin, pungency in black pepper are directly tied to soil moisture levels at critical growth stages. The table below summarizes the water requirements and critical stress-sensitive stages of major spice crops (Branco et al., 2026).

Table 1. Water requirements and critical moisture-sensitive stages of major spice crops

Crop	Botanical name	Water req. (mm/annum)	Critical stage
Chilli	*Capsicum annuum L.*	1,000–1,500	Flowering and fruiting
Black Pepper	*Piper nigrum L.*	2,000–3,000	Flowering and fruiting
Cardamom	*Amomum subulatum Roxb.*	1,500–2,500	Throughout growing season
Turmeric	*Curcuma longa L.*	1,200–1,500	Rhizome development
Cumin	*Cuminum cyminum L.*	250–450	Seed filling stage
Garlic	*Allium sativum L.*	700–1,000	Bulb development

Conventional flood irrigation with field efficiencies rarely exceeding 40 per cent, cannot reliably deliver the precise, consistent moisture that these crops demand at critical stages. The result is yielding penalties, suppressed quality and lost income that micro-irrigation is specifically designed to prevent.

3. Types of micro-irrigation systems

Micro-irrigation is not a single technology but a family of systems united by the principle of applying water slowly, frequently and precisely in the crop root zone. The main systems used in spice crop cultivation are described below.

3.1 Drip irrigation

The most widely adopted and water-efficient form of micro-irrigation which delivers water through emitters placed along lateral pipes positioned close to each plant row. It achieves water-use efficiencies of 90 to 95 per cent which is the benchmark for all irrigation methods. For row crops such as chilli, cumin, fenugreek and garlic arrangements of one or two laterals per row allow accurate targeted moisture delivery. Drip irrigation is equally suitable for orchard and plantation spice crops (Keykhayei et al., 2025).

3.2 Micro-sprinkler and mini-sprinkler irrigation

Micro-sprinklers distribute water over a small area around the plant through low-pressure sprinklers, creating a uniformly wetted zone. They are particularly valuable for cardamom and black pepper where maintaining canopy humidity is as important as soil moisture. Mini-sprinklers operate on the same principle but cover a larger wetted area making them suitable for wider plant spacings in plantation crops (Keykhayei et al., 2025).

3.3 Subsurface drip irrigation (SDI)

SDI buries drip laterals at depths of 20 to 45 cm directly within the root zone. By eliminating surface evaporation SDI achieves the highest water-use efficiency of any irrigation method upto 95 to 98 per cent. It also prevents weed germination from surface wetting, protects pipes from physical damage and enables precise in-situ delivery of water and nutrients. SDI is especially valuable in the arid and semi-arid environments where cumin, coriander and fenugreek are grown (Keykhayei et al., 2025).

3.4 Bubbler irrigation

In bubbler systems water is delivered as small streams at the base of individual plants. It is used primarily for deep-rooted plantation crops and fruit trees with high soil infiltration rates. Its simpler design and lower susceptibility to emitter clogging

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make it a low-maintenance option for certain tree spices (Keykhayei et al., 2025).

4. Advantages of micro-irrigation in spice crops

4.1 Dramatic water savings

The advantage of micro-irrigation is the reduction in water consumption. Drip and SDI systems consistently save 30 to 70 per cent of irrigation water compared with conventional flood irrigation by eliminating the three main pathways of water loss *i.e.* surface runoff, deep percolation beyond the root zone and evaporation from the soil surface (Ramya and Kumar, 2024). Singh *et al.* (2026) demonstrated that drip fertigation in cumin achieved a 45 per cent reduction in irrigation water use while simultaneously increasing yield by more than 30 per cent over conventional flood-irrigated plots.

4.2 Higher yields and better produce quality

Across all major spice crops, micro-irrigation steadily produces higher yields than flood irrigation because the root zone remains in an optimal moisture range throughout the crop cycle. For high-value spice crops, quality parameters which directly determine market price are significantly improved when crops are not subjected to moisture stress at critical stages. In cumin, drip fertigation improved essential oil content and 100 seed weight resulting in a more aromatic and heavier seed that commands premium prices (Singh et al., 2026). In large cardamom, micro-sprinkler irrigation with nutrient management significantly enhanced capsule yield and water productivity in sub-Himalayan growing conditions (Lepchaa et al., 2024). In chilli, subsurface and surface drip irrigation maintained adequate soil moisture through the flowering and fruiting stage, preventing the fruit-size reduction and capsaicin loss that moisture deficit causes (Demir et al., 2022). In garlic, drip irrigation increased bulb diameter and marketable yield while simultaneously reducing weed biomass from approximately 350 g to just 90 g per plot (Ghanbari et al., 2013).

4.3 Superior water-use efficiency

Water-use efficiency (WUE) is the ratio of marketable yield produced per unit of water consumed is the central metric by which irrigation technologies are evaluated in water-scarce agriculture. In fenugreek, micro-irrigation under different planting patterns demonstrated significantly higher WUE than conventional irrigation enabling more crop to be produced from each litre of water applied (Meena et al., 2017). In chickpea-coriander intercropping in Chhattisgarh, micro-irrigation methods outperformed indigenous flood methods on yield, biomass and WUE across both crops in the intercrop system (Kumar and Katre, 2018).

4.4 Precision nutrition through fertigation

Fertigation is the injection of soluble fertilizers directly into the irrigation stream where micro-irrigation exceeds conventional irrigation in its management potential. In a drip fertigation system, a venturi injector or injection pump places dissolved fertilizer into the main water supply and it reaches every emitter at a precise concentration, timed to match the crop's phenological requirements (Sureshkumar et al., 2017). For spice crops, which have distinctly different nutrient demands between vegetative growth, flowering and quality-formation stages this stage-specific delivery capability is transformative. Nitrogen can be front-loaded during rapid vegetative growth and reduced during seed filling, Potassium can be increased during fruiting to enhance essential oil synthesis in cumin and capsaicin accumulation in chilli. Singh *et al.* (2026) demonstrated that drip fertigation in cumin improved both agronomic efficiency and economic profitability simultaneously confirming that the water and nutrient management benefits compound each other.

4.5 Weed suppression

Economically significant advantages of drip and SDI systems is weed suppression because water is applied only to the crop root zone where the inter-row soil surface remains dry, depriving weed seeds of the

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moisture they need to germinate and establish. In garlic, Ghanbari *et al.* (2013) documented a dramatic reduction in weed biomass under drip irrigation compared to furrow and sprinkler methods. For a labour-intensive crop like garlic, where manual weeding can account for 15 to 20 per cent of total production costs, this weed-suppression effect translates directly into cost savings.

4.6 Greater economic returns

Higher yields, better quality, reduced water consumption, lower fertilizer expenditure and lower weed management costs collectively produce higher net returns and more favourable benefit-to-cost ratios than conventional irrigation. Government subsidy support under the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) and the Micro Irrigation Fund (MIF) substantially reduces the farmer's capital burden with subsidies covering 55 per cent of system cost for small and marginal farmers under the Per Drop More Crop (PDMC) component of PMKSY, shortening payback periods to one or two seasons in many spice-growing regions.

4.7 Environmental sustainability

Beyond the farm gate, micro-irrigation delivers environmental benefits of growing significance in the context of climate change and groundwater depletion. By reducing deep percolation, it minimises the leaching of soluble agrochemicals including nitrogen and pesticides into groundwater. By reducing surface runoff, it lowers soil erosion and sediment transport. By raising water-use efficiency, it slows the depletion of aquifers that are already overdrawn in major spice-growing regions. Micro-irrigation is a climate-smart technology that aligns economic productivity with ecological responsibility (Ramya and Kumar, 2024).

5. Policy support and the technology ecosystem

India's transition from flood to micro-irrigation has been substantially shaped by government policy interventions. The Centrally Sponsored Scheme on Micro Irrigation launched in 2006 and upscaled to the National Mission on Micro Irrigation (NMMI) in 2010 established the policy framework. The landmark transition came in 2015 with the launch of the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) under the motto "Har Khet Ko Pani, More Crop Per Drop," which unified all water-related schemes under one umbrella and placed micro-irrigation at the centre of India's agricultural water management strategy. The Micro Irrigation Fund (MIF) established through NABARD provides concessional financing to state governments for large-scale micro-irrigation infrastructure. Together, these instruments have driven the area under micro-irrigation in India from under 2 million hectares in 2010 to over 10 million hectares by 2024. The private technology ecosystem has grown in parallel with companies such as Jain Irrigation Systems, Netafim India, Mahindra EPC Irrigation, Automat Industries and Green Gold Irrigation supply turnkey drip and sprinkler systems across the country backed by field advisory services and design support. For spice-crop farmers many of whom are small holders this combination of government subsidy and private technical support has made micro-irrigation increasingly accessible.

6. Limitations and the path forward

Micro-irrigation is not without limitations because the high upfront capital cost of installation encompassing pipes, emitters, filters, pressure regulators and fertigation units remains the most significant barrier to adoption by resource-poor farmers, even with subsidy support. Emitter clogging, particularly in areas with hard water high in dissolved minerals requires regular maintenance and water quality management. The technology demands a minimum level of technical literacy for system design, operation and troubleshooting that is not yet universal at the farm level in India. The most promising development is the integration of micro-irrigation with sensor-based precision agriculture, real-time soil moisture sensors, weather-adaptive irrigation scheduling and IoT-enabled automated

control systems. Since 2020, pilot projects combining drip irrigation with artificial intelligence and precision monitoring have demonstrated further reductions in water use and further improvements in crop performance. For spice crops, where small improvements in essential oil content or seed quality translate into substantial price premiums these precision systems represent the next frontier in irrigation-driven value creation.

7. Conclusion

Micro-irrigation in spice crop cultivation delivers consistent improvements in yield, produce quality, water-use efficiency, weed suppression and economic returns. Drip irrigation, micro-sprinkler systems and subsurface drip irrigation each suited to specific crop and soil conditions enable spice farmers to produce more from less water, more yield, more quality, more income per unit of water. When coupled with fertigation, these systems become comprehensive precision management tools that address the two most critical inputs in spice cultivation simultaneously. India's water future will be defined by how successfully it transitions from flood to precision irrigation across its major crop systems. In spice cultivation where water sensitivity is high, quality premiums are large and the farming landscape is dominated by small and marginal farmers. Micro-irrigation is not just the most efficient option but it is the essential option. The principle that should guide every spice farmer, every extension worker and every policymaker is the one that has long guided modern irrigation science: "More Crop Per Drop, More Profit Per Field, More Sustainability Per Generation."

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Minor Fruits, Major Potential: A New Era of Horticulture

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Minor fruits constitute an important group of fruit crops that are generally less cultivated and commercially exploited than major fruit crops, but they possess considerable nutritional, medicinal, ecological and economic importance. India is endowed with a rich diversity of minor fruits because of its varied agro-climatic conditions. Fruits such as bael, wood apple, amra, carambola, tamarind, khejari, pilu, Ker, dragon fruit, jamun, badhar, fig, phalsa and karonda are well adapted to different environmental conditions and many of them can grow successfully under marginal and stress-prone conditions. These fruits are rich sources of vitamins, minerals, antioxidants, dietary fibre and several bioactive compounds. They are also used in traditional medicine, beverages, pickles, preserves, chutneys, jams and other processed products. Several minor fruits have good potential for value addition, livelihood generation and diversification of horticultural production. Their promotion can contribute to nutritional security, conservation of plant genetic resources and sustainable horticulture. Proper research, improved planting material, standard production technologies, post-harvest management and market development are required to increase their commercial utilization.

Introduction

Fruit crops are an important component of Indian agriculture because they provide essential nutrients, vitamins, minerals, antioxidants and other health-promoting compounds. Fruits such as mango, banana, citrus, guava, apple and grapes are generally considered major fruit crops because of their large-scale cultivation, commercial importance and established markets. In contrast, several fruit species remain relatively less cultivated, less researched and less commercially exploited and are commonly referred to as minor fruits.

Minor fruits are not necessarily inferior to major fruits in nutritional or economic value. In many cases, they are highly nutritious, medicinally important and well adapted to local environmental conditions. Several minor fruit crops can tolerate drought, salinity, poor soil, high temperature and other adverse conditions. Therefore, these crops can play an important role in climate-resilient and sustainable horticulture.

India possesses enormous diversity of minor fruits due to its diverse climate, soil and topography. Many species are traditionally grown in homesteads, wastelands, arid regions, tribal areas and rural landscapes. However, their potential remains underutilized because of limited scientific research, inadequate quality planting material, poor post-harvest handling, lack of organized marketing and low consumer awareness.

The conservation and promotion of minor fruits can help in preserving indigenous genetic resources while providing additional income to farmers. Their fruits can be consumed fresh or processed into jams,

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jellies, beverages, pickles, squashes, candies and other value-added products.

Major and minor fruits: A brief comparison

Major fruits	Minor fruits
Generally cultivated on a large commercial scale	Usually cultivated on a smaller scale
Well-established production and marketing systems	Limited organized marketing
Greater research and technological support	Comparatively less researched
Widely available in markets	Often locally available or seasonal
Usually have standardized production practices	Traditional production practices are common
High commercial importance	High potential nutritional, medicinal and ecological importance

Important minor fruits of India:

1.Bael: *Aegle marmelo,* **Family-** Rutaceae, **Origin-** India

- **Climatic requirement:** required and tropical and subtropical climate
- **Distribution** – U.P, Bihar, Jharkhand, west Bengal, Rajasthan.
- **Use-** ripe fruit are eaten fresh and use for making squash, jam jelly
- **Imp-** nutritious and medicinal fruits, rich in vitamin and minerals

2.Wood apple: *Limonia acidissino,* **Family-** Rutaceae

- **Origin-** India and Sri Lanka
- **Climatic requirements-** Tropical and sub-tropical
- **Distribution-** India, Sri Lanka, Bangladesh, Pakistan
- **Uses-** to prepare juice, squash, sherbet, jam and jelly
- **Importance-** have nutritional and medicinal value.

3.Amra: Spondias pinnata**, Family-** Anacardiaceae

- **Origin-** India
- **Climatic requirements-** tropical and subtropical climate
- **Distribution-** assam, west Bengal, Bihar, Odisha
- **Uses-** eaten fresh and used for making pickles, chutney, juice,
- **Importance-** have nutritional value and medicinal properties.

4.Carambola*: Averrhoa carambola,* **Family-** Oxalidaceae

- **Origin-** Sri Lanka and southeast Asia
- **Climate -** Tropical and sub-tropical and warm and humid conditions
- **Distribution-** India, Sri Lanka, Thailand
- **Uses-** eaten fresh and making juice, squash, jam, jelly and pickle.
- **Importance-** rich in vitamin C, anti-oxidants and have good market and nutritional value.

5. Tamarind: *Tamarindus indica,* **Family-** Fabaceae, **Origin-** Tropical Africa

- **Climate-** Tropical and sub-tropical
- **Distribution-** India, Sri Lanka, Myanmar, Thailand
- **Uses-** used as a spice, chutney, pickles, drinks

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- **Importance-** nutritional value like vitamins, minerals. And medicinal properties

6. **Khejri:** *Prosopis cineraria*, **Family**- Fabaceae, **Origin**- India

- **Climate-** hot and dry, arid and semi-arid climate.
- **Distribution-** Rajasthan, Haryana, Punjab, Gujrat, Uttar Pradesh
- **Uses-** leaves and pods are use for fodder and wood is use fuel and timber
- **Importance-** multipurpose tree of arid region, help in nitrogen fixation

7. **Pilu:** *Salvadora persica*, **Family:** Salvadoraceae

- **Origin-**India and other arid regions
- **Climate-** hot and dry, arid climate
- **Distribution-** Rajasthan, Gujarat, Punjab, Haryana
- **Uses-** eaten fresh and used for making pickles and other preparations
- **Importance-** have traditional and medicinal value

8. **Kair:** *Capparis decidua,* **Family-** Capparaceae

- **Origin:** India subcontinent
- **Climate**- hot dry and arid climate
- **Distribution-** Rajasthan, Gujarat, Punjab, Haryana
- **Uses-** use as vegetables pickles and traditional food preparations
- **Importance-** provides food and income in dry area

9. **Dragon fruits**: *Selenicereus undatus*, **Family-** Cactaceae

- **Origin-** Central and south America
- **Climate-** tropical and sub-tropical
- **Distribution-** Vietnam, Thailand, Malaysia, China
- **Uses-** eaten fresh and used for making juice, jam, jelly and ice cream
- **Importance-** rich in vitamin C, anti-oxidants and dietary fibre

10. **Jamun:** *Syzygium cumini,* **Family:** Myrtaceae, **Origin-** India

- **Climate**- tropical and sub-tropical
- **Distribution-** Uttar Pradesh, Tamil Nadu and Maharashtra.
- **Uses-** eaten fresh and used for making juice, jam, jelly, vinegar
- **Importance-** rich in antioxidants and minerals

11. **Barhal**: *Ziziphus mauritina*, **Family-** Rhamnaceae, **Origin**- India

- **Climatic –** tropical and subtropical climate
- **Distribution-** Rajasthan, Uttar Pradesh, Punjab and Haryana
- **Uses-** eaten fresh and used for making juice, jam, jelly
- **Importance:** provides nutritious and income to farmers

12. **Fig:** *Ficus carica,* **Family:** Moraceae, **Origin-** Western Asia

- **Climate-** warm, dry, and subtropical
- **Distribution-** turkey, Iran, USA, India
- **Uses-** eaten fresh and used for making juice, jam, jelly
- **Importance-** provides nutritious and income to farmers

13. **Phalsa:** *Grewia asiatica,* **Family:** Malvaceae, **Origin**- India

- **Climate-** tropical and sub-tropical
- **Distribution-** Uttar Pradesh, Punjab, Haryana

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- **Uses-** eaten fresh and used for making juice, jam, jelly
- **Importance-** nutritional value like vitamins, minerals.

14. **Karonda:** *Carissa carandas,* ***Family-*** Apocynaceae, **Origin-** India

- **Climate-** tropical and sub-tropical
- **Distribution-** Bihar, Uttar Pradesh, Maharashtra
- **Uses-** uses for making pickles, chutney, jam and jelly
- **Importance-** nutritional value, Etc.

Nutritional Importance:

Minor fruits are rich sources of vitamins, minerals, dietary fibre, antioxidants and other beneficial bioactive compounds. Fruits such as bael, jamun, phalsa and karonda provide important nutrients required for a healthy diet. Many of these fruits contain vitamin C, iron, calcium, potassium and phenolic compounds. Regular consumption can support dietary diversification and nutritional security. Thus, minor fruits can be valuable components of a balanced diet.

Medicinal and Traditional Importance:

Many minor fruits have been traditionally used in Indian systems of medicine and local healthcare practices. Bael is traditionally valued for digestive health, while jamun, tamarind, karonda and phalsa are also used for various traditional purposes. Their fruits and other plant parts contain bioactive compounds with antioxidant properties. These crops have been used traditionally in beverages, remedies and household preparations. Therefore, minor fruits have significant cultural and traditional importance.

Economic Importance and Value Addition:

Minor fruits provide opportunities for additional income, particularly for small and marginal farmers. Their fruits can be processed into jams, jellies, pickles, squashes, juices, candies, syrups and other products. Value addition improves shelf life, reduces post-harvest losses and increases the market value of the produce. Small-scale processing units can also generate rural employment. Hence, minor fruits have good potential for entrepreneurship and rural economic development.

Role in Sustainable Horticulture:

Several minor fruits are hardy and well adapted to drought, poor soils and other adverse environmental conditions. Crops such as bael, karonda, kair, khejari and pilu can be useful in dryland and marginal areas. Their cultivation helps conserve indigenous plant diversity and utilize otherwise less productive lands. They can also support agroforestry, biodiversity and climate-resilient farming systems. Thus, minor fruits can contribute to sustainable and resource-efficient horticulture.

Future Scope:

There is considerable scope for increasing the production and commercial utilization of minor fruits in India. Research is needed on improved varieties, propagation, production technology, pest management and post-harvest handling. Development of attractive value-added products can increase consumer demand and farmer income. Better marketing, processing facilities and quality planting material can further promote their cultivation. Greater awareness among farmers and consumers will help bring these underutilized fruits into mainstream horticulture.

Conclusion:

Minor fruits are an important component of India's horticultural biodiversity with nutritional, medicinal, economic and ecological value. Their adaptability to diverse and difficult environments makes them suitable for sustainable horticultural production. Processing and value addition can increase their economic importance and reduce post-harvest losses. Promotion of these crops can support nutritional security, livelihood generation and biodiversity conservation. Therefore, greater research, cultivation

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and commercialization of minor fruits are essential for the future of Indian horticulture.

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Changing Climate, Changing Agriculture: Challenges and Opportunities

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Climate change has become a major challenge for agriculture, affecting crop production, livestock, soil health and water availability through rising temperatures, irregular rainfall, droughts, floods, heat waves and changing pest and disease patterns. However, it also provides an opportunity to transform agriculture through climate-resilient varieties, crop diversification, efficient irrigation, rainwater harvesting, conservation agriculture, agroforestry and improved weather information. Climate-smart agriculture can enhance productivity, farm income and resilience while reducing environmental impacts. The future of agriculture will depend on coordinated efforts by farmers, scientists, policymakers and communities. Greater emphasis on climate information, early-warning systems, sustainable water management, affordable technologies and financial support can help farmers adapt effectively. Thus, changing climate requires a shift towards **resilient, resource-efficient, sustainable and knowledge-based agricultural systems** capable of ensuring food security and livelihoods for future generations.

Introduction

Agriculture has always been closely connected with climate, but the relationship is becoming increasingly difficult to manage. Farmers traditionally depend on seasonal rainfall, temperature patterns and predictable growing seasons to decide what to grow and when to sow, irrigate and harvest. Climate change is making many of these conditions less predictable. Increasing temperatures, changing rainfall distribution, droughts, floods and extreme heat events can reduce crop yields, affect livestock productivity and increase pressure on already limited water and soil resources. The IPCC has reported that climate change is already affecting food security through impacts on food availability, access, utilization and stability.

The challenge is particularly important for developing countries where large numbers of rural households depend directly or indirectly on agriculture. Smallholder farmers are often exposed to climatic risks while having limited access to irrigation, credit, crop insurance, improved technologies and reliable weather information. Recent evidence also indicates that climate change has slowed global agricultural productivity growth, demonstrating that climate impacts are not simply future possibilities but are already influencing agricultural development.

At the same time, agriculture has considerable potential to become part of the solution. Sustainable soil management, improved water-use efficiency, agroforestry, crop diversification, conservation agriculture, precision farming and climate-resilient crop varieties can help farmers cope with changing conditions. FAO emphasizes that transforming agrifood systems can simultaneously strengthen resilience, improve food security and contribute to climate action.

Changing Climate: Major Challenges for Agriculture

1. Rising temperature

Higher temperatures can shorten crop growth periods and increase evaporation and crop water requirements. Heat stress during flowering and grain-filling stages can significantly reduce yields in

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sensitive crops. Livestock are also affected by heat stress through reduced feed intake, growth, reproduction and milk production.

2. Changing rainfall patterns

The issue is not simply whether annual rainfall increases or decreases. **When, where and how rainfall occurs** is equally important. Heavy rainfall over a short period may cause flooding and soil erosion, while long dry periods can create severe moisture stress. This makes traditional farming calendars increasingly uncertain.

3. Drought and water scarcity

Agricultural drought is becoming a major concern in many regions. Competition for water among agriculture, domestic use and industry is expected to increase. Efficient irrigation, groundwater management, rainwater harvesting and soil-moisture conservation will therefore become increasingly important.

4. Extreme weather events

Floods, cyclones, heat waves, storms and prolonged droughts can destroy crops within a short period. FAO reports that agriculture bears a substantial share of disaster-related losses, highlighting the need for stronger disaster preparedness and resilient agricultural infrastructure.

5. Emerging pests and diseases

Changing temperature and humidity can influence the distribution, survival and reproduction of insects and pathogens. Consequently, farmers may encounter pests and diseases in areas or seasons where they were previously uncommon.

6. Food and livelihood insecurity

Reduced productivity can increase food prices and affect household incomes. Climate-related agricultural losses can be particularly serious for farming households that depend primarily on a single crop or livestock activity.

Opportunities: Changing Agriculture for a Changing Climate

Climate change requires farmers to move from **risk response to risk anticipation**. Several approaches can help achieve this transition.

Climate-resilient crops

Breeding and adoption of drought-tolerant, heat-tolerant, flood-tolerant, salt-tolerant and short-duration crop varieties can reduce climate-related production losses. Local adaptation is important because the best variety for one region may not necessarily perform well in another.

Crop diversification

Growing different crops rather than depending on a single crop can reduce economic and production risks. Intercropping, crop rotation and integrated farming can also improve resource utilization and soil health.

Efficient water management

Drip and sprinkler irrigation, rainwater harvesting, farm ponds, mulching, soil-moisture conservation and improved irrigation scheduling can help produce more agricultural output with less water.

Conservation agriculture

Minimum soil disturbance, crop residue management and crop diversification can improve soil structure, reduce erosion and enhance water retention. Such practices can be particularly valuable under increasing rainfall variability.

Agroforestry

Combining trees with crops and/or livestock can provide multiple benefits, including shade, improved microclimates, additional farm products, carbon storage and protection against wind and soil erosion.

Digital and climate information services

Weather forecasts, seasonal climate information, mobile-based advisories, remote sensing and precision agriculture can help farmers make better

decisions regarding sowing, irrigation, fertilizer application and pest management. Recent research identifies digital advisory services and access to information as important factors supporting adoption of climate-smart agriculture.

Climate-smart agriculture

Climate-smart agriculture seeks to increase productivity and income, strengthen adaptation and resilience, and reduce or avoid greenhouse-gas emissions where feasible. Evidence from recent reviews suggests that combinations of climate-smart practices can improve farm productivity, income, resource-use efficiency and resilience, although outcomes depend on local conditions and farmer circumstances.

Conclusion

Climate change is creating a new reality for agriculture. Farmers can no longer rely entirely on historical weather patterns to make production decisions. Rising temperatures, irregular rainfall, droughts, floods and extreme events are increasing production risks and threatening food and livelihood security. Scientific evidence confirms that climate change has already affected agricultural productivity and food systems, making adaptation an immediate requirement rather than a future option.

Yet the changing climate also provides an opportunity to transform agriculture. The solution is not a single technology or farming practice. Instead, resilience will come from combining **better crops, better water management, healthier soils, diversified farming systems, climate information, digital technologies and supportive policies**. Climate-smart agriculture can provide an important framework for bringing these approaches together.

Farmers should be supported to move from reactive decisions to informed and anticipatory management. Early-warning systems, reliable weather forecasts, crop insurance, affordable credit, extension services and accessible technologies can significantly improve their ability to manage climate risks. Special attention should be given to small and marginal farmers because they are often the least equipped to absorb climate-related losses.

The future agricultural system must therefore be **productive, profitable, resilient and environmentally responsible**. Agriculture should not merely survive climate change; it should evolve in response to it. The central message is simple: **if the climate is changing, agriculture must change with it.** Through scientific innovation, farmer knowledge, appropriate policies and responsible management of natural resources, climate challenges can become opportunities to build a stronger and more sustainable agricultural future.

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Farmers of the Future: Using Technology to Beat Weather Uncertainty

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Weather uncertainty is becoming one of the major challenges affecting agricultural productivity, farm income and food security. Farmers increasingly face irregular rainfall, heat waves, droughts, floods and shifting crop seasons. Modern technologies such as artificial intelligence, remote sensing, Internet of Things (IoT), mobile-based weather advisories, drones, satellite observations and digital decision-support systems can help farmers anticipate weather risks and make timely decisions. Weather forecasts combined with field-level information can guide sowing, irrigation, fertilizer application, pest management and harvesting. The future of farming therefore depends not only on better weather prediction but also on converting forecasts into simple, location-specific and actionable advice. Affordable technology, local-language communication and farmer training will be essential for ensuring that these innovations reach small and marginal farmers.

Introduction

Agriculture has always been closely connected with weather, but the relationship is becoming more challenging as climate variability increases. Rainfall that once followed relatively familiar seasonal patterns can now arrive late, occur in intense bursts or stop for extended periods. Episodes of extreme heat, drought and heavy rainfall can occur at critical stages of crop development, causing substantial losses. Consequently, farmers need more than traditional experience to manage increasingly uncertain weather conditions.

Technology is providing new ways to reduce this uncertainty. Modern weather forecasting combines observations from satellites, weather stations, radar systems and numerical weather prediction models. Artificial intelligence and machine learning are increasingly being used to analyse large datasets and improve prediction and decision-support systems. Digital technologies can also connect weather information with crop, soil and field conditions, allowing farmers to receive advice that is more relevant to their individual farming situations. Recent research highlights the growing importance of integrating digital technologies with climate-change adaptation in agriculture.

The most useful development is not simply providing a forecast such as "rain is expected tomorrow." Farmers need information translated into an agricultural decision: whether to irrigate, spray a pesticide, sow a crop, apply fertilizer, postpone harvesting or protect harvested produce. Agrometeorological services are increasingly designed around this principle. FAO notes that weather and agrometeorological advisories can support decisions related to sowing, irrigation, fertilizer management, pest and disease control and harvesting.

Technology as a Weather-Management Tool

1. Artificial Intelligence and Machine Learning

Artificial intelligence can process large quantities of historical and real-time weather, soil and crop data. Machine-learning models can identify relationships that may be difficult to detect using conventional approaches. These technologies have potential applications in rainfall prediction, crop-yield forecasting, drought assessment, pest surveillance and early-warning systems.

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In India, AI-based weather forecasting has also begun to be used for farmer communication. In 2025, an Indian government initiative disseminated AI-based monsoon forecasts to millions of farmers, demonstrating the potential of combining advanced forecasting with large-scale mobile communication.

2. Remote Sensing and Satellites

Satellite imagery allows agricultural scientists and farmers to observe crop conditions over large areas. Changes in vegetation, crop moisture and land-surface characteristics can be monitored without visiting every field.

Remote sensing can help identify drought stress, excessive moisture, crop damage and variations in crop growth. When satellite information is combined with ground observations and weather forecasts, it can become a powerful tool for agricultural decision-making.

3. Internet of Things and Smart Sensors

IoT-based sensors can collect field-level information on soil moisture, temperature, humidity and other environmental parameters. Farmers can use these observations to determine whether irrigation is actually required rather than relying only on fixed irrigation schedules.

Smart irrigation systems can therefore reduce unnecessary water use while maintaining adequate moisture for crops. Similarly, sensors inside protected cultivation structures can help regulate temperature, humidity and irrigation.

4. Mobile-Based Agro-Advisories

Mobile phones provide one of the simplest ways to transfer scientific information from forecasting agencies to farmers. Weather forecasts, rainfall warnings, pest alerts and crop-management recommendations can be delivered through SMS, mobile applications, WhatsApp and voice-based systems.

Recent studies show that weather and climate information can be connected with climate-smart practices such as irrigation, water harvesting, crop protection and crop management.

For farmers with limited literacy or internet access, voice messages and local-language advisories can be particularly important. Digital agricultural initiatives are increasingly exploring AI-based systems that provide information through text, voice and images.

5. Drones and Precision Agriculture

Drones can provide high-resolution information about crop conditions. Farmers and agricultural professionals can use drone imagery to identify stressed areas, nutrient deficiencies, waterlogging and pest-affected patches.

Instead of treating an entire field uniformly, precision agriculture allows inputs to be targeted where they are needed. This approach can potentially reduce wastage of water, fertilizers and crop-protection products while improving resource-use efficiency.

From Weather Forecast to Farm Decision

The real value of technology lies in converting weather information into an actionable recommendation. For example:

Weather information	Possible farm decision
Heavy rainfall expected	Delay irrigation and protect harvested produce
Dry period predicted	Plan irrigation and moisture conservation
High temperature forecast	Adjust irrigation and protect sensitive crops
Strong winds expected	Secure protected structures and postpone spraying

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High humidity predicted	Increase monitoring for fungal diseases
Delayed monsoon onset	Reconsider sowing date or crop choice
Extreme rainfall warning	Improve drainage and protect vulnerable fields

Such decision-support systems can reduce the gap between meteorological information and practical farming. Research from India has demonstrated the usefulness of contextualized weather-based advisories, while also showing that farmers' decisions depend on local conditions, traditional knowledge and the type of agricultural activity involved.

Challenges for Farmers of the Future

Technology alone cannot eliminate weather risk. Several barriers must be addressed before digital agriculture can benefit farmers on a large scale.

First, many small and marginal farmers have limited access to reliable internet connectivity, smartphones, sensors and other digital infrastructure. Second, advanced technologies can be expensive and difficult to operate without technical support. Third, forecasts are never perfectly accurate; therefore, advisory systems must communicate uncertainty rather than presenting predictions as guaranteed outcomes.

Digital literacy is another important issue. Farmers need to understand not only how to receive an advisory but also how to interpret and apply it. Recent research from Tamil Nadu indicates that institutions and local change agents can play an important role in improving the adoption of digital climate-smart agricultural practices.

There is also a need for better localization. A forecast covering an entire district may not adequately represent conditions in an individual village or field. The future of agricultural advisories should therefore combine weather forecasts with local observations, soil characteristics, crop stage and farmer knowledge.

The Future: Connected and Climate-Resilient Farming

The future agricultural system is likely to become increasingly connected. Weather stations, satellites, sensors, mobile phones, artificial intelligence and farm-management platforms can work together as an integrated decision-support network.

A farmer may eventually receive an advisory such as: “Rain is likely within the next 24 hours; postpone irrigation and fertilizer application.” Such a message is more useful than a general weather forecast because it directly addresses the farming decision.

India has considerable potential in this area because of its large agricultural research network, satellite infrastructure, mobile connectivity and growing digital ecosystem. Recent work has also emphasized the importance of assessing differences in digital readiness among Indian states before implementing climate-smart digital agriculture and irrigation systems.

However, the objective should not be to replace farmers' knowledge with technology. Instead, technology should strengthen farmers' ability to combine scientific information with local experience. The most successful systems will be those that are affordable, understandable, locally relevant and designed around actual farmer needs.

Conclusion

Weather uncertainty cannot be completely removed, but its impact on agriculture can be reduced through timely information and better decisions. Artificial intelligence, satellite remote sensing, IoT sensors, drones, mobile applications and digital advisory platforms are creating new opportunities for climate-resilient farming. The most important transition is from simply predicting weather to providing **decision-oriented agricultural advice**.

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Farmers of the future will not necessarily be farmers who use the most sophisticated technology. They will be farmers who can access reliable information at the right time and convert it into appropriate action. For this transformation to become inclusive, governments, meteorological agencies, agricultural universities, technology companies, extension organizations and farmer groups must work together. Affordable technology, local-language communication, reliable connectivity and farmer training will determine whether digital agriculture becomes a practical solution or remains available only to technologically advanced farms.

The future of farming, therefore, is not technology replacing traditional agriculture—it is science, technology and farmer knowledge working together to make agriculture more resilient to an uncertain climate.

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Flying Farmers: How Drones Can Improve Crop Production

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Agriculture is rapidly moving from traditional field-based management toward data-driven and precision farming systems. Among the emerging technologies, agricultural drones, or Unmanned Aerial Vehicles (UAVs), are becoming valuable tools for improving crop production, resource-use efficiency and farm management. Drones equipped with RGB, multispectral, hyperspectral and thermal sensors can provide high-resolution information about crop growth, plant health, soil variability, water stress, nutrient deficiency, weeds and pest or disease incidence. Unlike conventional field inspection, drone-based monitoring can cover large areas rapidly and identify variations within individual fields. This allows farmers to take timely and location-specific decisions regarding irrigation, fertilization, crop protection and other farm operations. Recent research also demonstrates the increasing use of artificial intelligence, machine learning and deep learning for processing drone images and converting them into useful information for farmers. Drones are additionally being used for precision spraying of pesticides and fertilizers, reducing unnecessary chemical application and improving operational efficiency. Yield estimation, crop counting, damage assessment and decision-support systems are other promising applications. Recent reviews indicate that drone technology is becoming an important component of precision and smart agriculture, although high initial investment, limited battery endurance, technical expertise, regulations, data management and lack of farmer training remain important constraints.

Introduction

The future of agriculture depends on producing more food while using limited land, water, labour and other natural resources efficiently. Climate variability, rising production costs, labour shortages, water scarcity and increasing pressure to reduce chemical inputs have encouraged farmers and researchers to adopt modern technologies. Precision agriculture provides an important pathway by enabling farmers to manage crops according to the actual conditions of different parts of a field.

In this technological transformation, **drones are becoming the new "eyes in the sky" for farmers**. Agricultural drones can fly over fields and collect detailed information that may not be visible during ordinary field visits. Modern UAVs can carry different sensors and produce high-resolution images of crops and soil. These data can subsequently be analysed to identify crop stress, disease, weeds, nutrient problems and water requirements.

1. Crop health monitoring

One of the most useful applications of drones is crop-health monitoring. Multispectral and hyperspectral cameras can detect changes in plant reflectance associated with crop stress before symptoms become clearly visible to the human eye. Vegetation indices such as NDVI can be used to identify differences in crop vigour and field variability. This enables farmers to inspect problem areas and take corrective action at an early stage.

2. Early detection of pests and diseases

Drones can help identify areas affected by insects, fungal diseases and other stresses. High-resolution imagery combined with machine learning and deep learning can classify plants and detect abnormal crop conditions. Early identification can help farmers

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apply crop-protection measures only where required rather than treating the entire field uniformly.

3. Precision spraying

Spraying is another important application. Drone-based spraying systems can deliver pesticides, nutrients and other agricultural inputs to specific areas. This approach can reduce unnecessary chemical application, labour requirements and field compaction. However, appropriate spray calibration, weather conditions, droplet characteristics and regulatory compliance are essential for safe and effective operation.

4. Irrigation and water management

Thermal and multispectral sensors can provide information related to crop water stress. Drone observations can therefore support irrigation scheduling and identification of areas receiving insufficient or excessive water. Integration of UAV observations with weather data and other precision-agriculture technologies could make irrigation management more efficient.

5. Weed management

Weeds compete with crops for water, nutrients, sunlight and space. Drone imagery can distinguish crop plants from weeds, particularly when combined with artificial intelligence. Farmers can then identify weed hotspots and undertake targeted control measures. This may reduce herbicide use and contribute to more environmentally responsible crop production.

6. Yield estimation

Another promising application is yield prediction. Drone images collected during different crop-growth stages can be combined with vegetation indices, crop characteristics and machine-learning models to estimate yield before harvesting. Recent research shows that combining different data sources with UAV spectral information can improve yield-estimation performance.

7. Artificial intelligence: Making drones smarter

The real strength of agricultural drones is not only their ability to fly and capture images, but also their ability to generate **actionable information**. Artificial intelligence and deep-learning algorithms can process large numbers of images and identify crop types, weeds, diseases, stress conditions and other field characteristics. The integration of UAVs with AI is therefore helping to shift agriculture from simple observation toward automated decision-making.

8. Drones and Indian agriculture

Drones have particular potential in India, where small and fragmented landholdings, labour shortages and the need for efficient input use create strong demand for affordable precision technologies. Recent research on India highlights opportunities in crop monitoring, precision farming and pesticide application, while also identifying challenges such as equipment cost, training, infrastructure and regulatory requirements.

9. Challenges ahead

Despite their advantages, drones are not a complete replacement for farmers or agricultural experts. Battery limitations, weather conditions, payload capacity, sensor costs, image-processing requirements and skilled-operation requirements can restrict their use. Farmers also need reliable interpretation of drone data rather than simply receiving large quantities of images. Regulatory compliance, privacy, data ownership and standardisation are additional concerns. Recent research suggests that successful adoption depends not only on better sensors but also on robust data processing, farmer training, economic feasibility and integration with other agricultural technologies.

Conclusion

Agricultural drones are transforming the way farmers observe and manage their fields. From crop-health monitoring and disease detection to precision spraying, irrigation management, weed identification

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and yield estimation, drones can provide timely and field-specific information for better decision-making. The combination of UAVs with artificial intelligence, machine learning, satellite observations, Internet of Things devices and weather information is likely to make precision agriculture increasingly powerful.

The future farmer may therefore not simply be a person working **on the field**, but also a person managing information **from above the field**. Nevertheless, widespread adoption will require affordable equipment, local technical support, farmer training, appropriate regulations and easy-to-use decision-support systems. If these challenges are addressed, drones can become an important tool for increasing productivity, reducing input wastage and promoting climate-smart and sustainable agriculture. Recent literature from 2026 continues to identify UAVs as an important part of the transition toward data-driven, sustainable crop production.

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A New Path in Ragi Cultivation
How to Increase Yield and Improve Farmers' Income

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Ragi, also known as finger millet, is one of the traditional millets of Tamil Nadu. In districts such as Dharmapuri, Krishnagiri and Salem, it has been an important crop for many generations, especially under rainfed conditions.

Ragi is a hardy crop. It can grow with relatively less water and can tolerate drought to some extent. It is also a nutritious food, rich in calcium, iron, dietary fibre and other nutrients. Because of its nutritional value, the demand for ragi is increasing once again.

But today, the question before a farmer is not simply, *"How do I grow ragi?"* Farmers also need to ask: Which variety should I select? When should I raise the nursery? When should I transplant? How much fertilizer is required? When should I irrigate? How can I control weeds and diseases? And how can I get a better price for my produce?

Finding practical answers to these questions is the key to making ragi cultivation more profitable.

Choosing the Right Variety

The first step towards getting a good yield is choosing a variety that suits the local soil, climate, rainfall and farming system.

In Dharmapuri, farmers are commonly interested in **Paiyur 2, ATL 1, GPU 28, GPU 67 and ML 365**. Each variety has its own advantages.

Paiyur 2 – A Suitable Choice for Dharmapuri

Paiyur 2 is an important ragi variety associated with the Paiyur Regional Research Station. It takes about **115 days** to mature and is particularly suitable for rainfed cultivation.

Its average rainfed grain yield is around **2,527 kg/ha**, with higher yields recorded under favourable conditions. It has good resistance to **leaf blast** and moderate resistance to neck and finger blast.

For farmers in the rainfed areas of Dharmapuri and neighbouring districts, Paiyur 2 remains an important variety to consider.

ATL 1 – Short Duration and Good Yield Potential

ATL 1 is an improved ragi variety developed by Tamil Nadu Agricultural University through the Agricultural Research Station, Athiyandal. It matures in approximately **105–110 days** and is suitable for both rainfed and irrigated conditions.

Research trials have recorded about **2,879 kg/ha under rainfed conditions** and **3,128 kg/ha under irrigated conditions**. The variety has a strong stem and relatively less lodging. It also has moderate resistance to leaf, neck and finger blast.

For farmers who want a shorter-duration crop with good yield potential, ATL 1 can be considered.

GPU 28 – Good Resistance to Blast Disease

GPU 28 is a popular ragi variety developed by the University of Agricultural Sciences, Bengaluru. It takes approximately **110–115 days** to mature and can be cultivated under both rainfed and irrigated conditions.

One of its important advantages is its **good resistance to blast disease**. Its reported yield potential is around **8–10 quintals per acre under**

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rainfed conditions and **13–15 quintals per acre under irrigated conditions**.

Farmers in areas where blast disease is a recurring problem can consider GPU 28 as one of the options.

GPU 67 – Short Plant and Less Lodging

GPU 67 is another important ragi variety developed by the University of Agricultural Sciences, Bengaluru. It was released in **2009** and has been recommended for several ragi-growing regions, including Tamil Nadu.

The plant is about **85–90 cm tall** and has a semi-dwarf nature. Its important characteristics include a strong stem, good tillering ability, less lodging and a plant structure suitable for mechanical harvesting.

According to UAS Bengaluru information, GPU 67 has a yield potential of approximately **1,000–1,200 kg per acre under rainfed conditions** and **1,400–1,600 kg per acre under irrigated conditions**.

However, actual yield can vary considerably depending on soil, rainfall, irrigation and crop management. Therefore, these figures should be treated as variety performance figures and not as a guaranteed yield for every farmer.

ML 365 – More Tillers and Shorter Duration

ML 365 is another variety that deserves attention in modern ragi cultivation. It takes about **105–110 days** to mature and has good tillering ability.

Its reported yield potential is around **8–10 quintals per acre under rainfed conditions** and **12–14 quintals per acre under irrigated conditions**. It also has moderate resistance to neck and finger blast.

ML 365 is particularly interesting for farmers who want to use **mat nursery and mechanical transplanting**.

A field study in Tamil Nadu also recorded good performance from ML 365. In one study conducted in Erode district, it recorded approximately **2,584.5 kg/ha grain yield**, with an average of **8.28 tillers per plant**.

Farmers interested in ML 365 can first try it on a small area and compare its performance with the variety they normally grow.

Five Ragi Varieties at a Glance

Variety	Duration	Main Advantage	Reported Yield Potential
Paiyur 2	~115 days	Suitable for Dharmapuri rainfed areas; leaf blast resistance	~2,527 kg/ha rainfed
ATL 1	105–110 days	Short duration, strong stem, blast resistance	~2,879 kg/ha rainfed; 3,128 kg/ha irrigated
GPU 28	110–115 days	Good blast resistance	8–10 q/acre rainfed; 13–15 q/acre irrigated
GPU 67	Medium duration	Short plant, less lodging	1,000–1,200 kg/acre rainfed; 1,400–1,600 kg/acre irrigated
ML 365	105–110 days	More tillers, short duration	8–10 q/acre rainfed; 12–14 q/acre irrigated

Note: These are research, trial or recommended yield figures. Actual farm yield will depend on soil,

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rainfall, seed quality, planting method, nutrient management, irrigation, weed control and disease management.

The Right Time for Nursery Raising in Dharmapuri

Many farmers in Dharmapuri follow the practice of raising ragi seedlings and transplanting them.

Based on local farming experience, **raising the nursery by around August 15 and completing transplanting in time to make good use of the monsoon** can give good results.

However, farmers should not follow the date blindly every year. Rainfall, soil moisture and local weather conditions should also be considered.

"Follow the season, not just the calendar."

Mat Nursery – The Foundation for Mechanical Transplanting

Mat nursery is particularly important when mechanical transplanting is planned.

For one hectare of main field, approximately **100 square metres, or 2.5 cents**, of nursery area may be sufficient. About **5 kg of good-quality seed** is required.

Prepare nursery beds about **1 metre wide and 5 cm high**. Spread a polythene sheet over the beds and place a mixture of:

60% fertile soil + 30% well-decomposed farmyard manure + 10% sand

to a thickness of about 2 cm.

Treat the seeds with **Azospirillum** and spread them evenly. Cover them lightly with soil and irrigate gently using a rose can.

The nursery should be kept moist, but **water should never be allowed to stagnate**.

With proper care, healthy seedlings can be ready for mechanical transplanting in about **15–18 days**.

Mechanical Transplanting – A Solution to Labour Shortage

Labour shortage has become an important challenge in agriculture. During the transplanting season, arranging a large number of workers at the same time is becoming increasingly difficult.

Mechanical transplanting can help reduce labour requirements and save time when the mat nursery is prepared properly.

But the machine alone is not the solution. **The nursery, seedling age, seedling thickness, field preparation and planting distance must all be planned together.**

A Progressive Farmer Who Has Tried the New Approach

Mr. Mathaiyan, a progressive farmer from the **Pennagaram Block of Dharmapuri District**, has tried modern methods in ragi cultivation.

His personal contact number is not included in this article.

What is particularly interesting about his approach is that he did not depend on one technology alone. He combined several practical methods.

He used **ML 365 in a mat nursery and followed it with mechanical transplanting**.

He also used:

- About 12.5 tonnes of well-decomposed farmyard manure per hectare
- Azospirillum
- Phosphobacteria
- Cono weeding at 20 and 40 days after transplanting
- Irrigation according to crop requirement, particularly during important growth stages

This is a good example of how several simple technologies can be combined to improve crop management.

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A successful practice in one farmer's field can become a useful lesson for many other farmers. That is why this experience deserves to be shared.

Feed the Soil First

Good yield begins with healthy soil.

Well-decomposed farmyard manure improves soil structure and helps the soil retain moisture.

Mr. Mathaiyan used **12.5 tonnes of well-decomposed farmyard manure per hectare**, along with biofertilizers such as Azospirillum and Phosphobacteria.

But there is one important point every farmer should remember:

Do not apply more fertilizer simply because you want more yield.

First test the soil and find out what nutrients are actually required. Then apply the right nutrients in the right quantity and at the right time.

Healthy soil is the foundation of sustainable farming.

The First 40 Days Are Very Important

Weed management is especially important during the early growth stages of ragi.

Weeds compete with the crop for water, nutrients, sunlight and space.

Mr. Mathaiyan used a **Cono weeder at 20 and 40 days after transplanting**.

Mechanical weeding at the proper stage can reduce weed competition and also improve aeration in the soil.

The first 40 days deserve special attention because good early crop growth has a strong influence on the final yield.

Water – Give It When the Crop Needs It

Ragi can tolerate drought to some extent, but that does not mean the crop needs no water.

The important crop stages are:

Seedling establishment → Tillering → Panicle formation → Flowering → Grain filling

Adequate soil moisture is particularly important during these stages.

Mr. Mathaiyan avoided unnecessary irrigation and provided water according to crop requirement, especially during **tillering and grain-filling stages**.

The simple lesson is:

Good irrigation does not mean giving more water. It means giving water at the right time.

Panicle Formation – A Critical Stage

The panicle formation stage is an important stage in ragi cultivation.

Farmers should regularly observe:

- Leaf colour
- Stem strength
- Panicle development
- Soil moisture
- Signs of disease

A farmer may not be able to visit the field every day, but regular field observation is important.

A farmer who carefully watches the crop can identify many problems before they become serious.

Blast Disease – Act Early

Blast is one of the major diseases affecting ragi.

Farmers should regularly inspect the **leaves, neck of the plant and finger heads**.

Early symptoms may appear as small lesions on the leaves. As the disease develops, the lesions may enlarge. When the neck of the plant is affected, the panicle may dry and hang down. This is known as **neck blast**.

If early symptoms are noticed, farmers should take action without delay.

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As recommended by Tamil Nadu Agricultural University, suitable fungicides such as **Carbendazim at 500 g/ha or Iprobenphos (IBP) at 500 ml/ha** may be used when symptoms appear, following the current label instructions and recommendations of the Agriculture Department.

Further protection may be required during the **flowering stage**, particularly for neck and finger blast.

For farmers following **natural or biological farming practices**, *Pseudomonas fluorescens* can be considered as a biological disease-management option based on expert recommendations. TNAU studies have reported that seed treatment and *Pseudomonas fluorescens* application can help in managing blast disease.

However, farmers should **not spray a fungicide without first confirming the disease**. When symptoms are noticed, it is better to show the affected plants or photographs to the local Agriculture Officer, KVK scientist or agricultural expert and obtain the correct recommendation.

"It is better to identify blast at the early stage and take timely action than to wait until the disease becomes severe."

Harvesting Is Not the End

A good yield is important, but harvesting is not the end of the farmer's work.

After harvesting, the ragi should be:

Threshed → Cleaned → Properly dried → Graded → Safely stored

The grain should be free from stones, soil, weed seeds and other impurities.

Proper drying is particularly important. Grain with excess moisture can deteriorate during storage.

Clean, properly dried and good-quality grain has a better chance of getting a good price.

Natural Ragi – Create a Separate Identity

Farmers following natural farming practices have an opportunity to create additional value from their ragi.

But naturally produced ragi should not simply be mixed with other grain.

A better approach is:

Separate production → Separate harvesting → Separate storage → Cleaning → Grading → Appropriate certification → Good packaging → FPO or direct consumer marketing

If the product is marketed as **"organic"**, the applicable certification and regulatory requirements should be followed.

Natural farming can create additional value, but **quality, traceability and consumer trust** are equally important.

Marketing – Think About the Market Before Harvest

A farmer should not wait until the day of harvest to start thinking about marketing.

Possible marketing channels include:

- Government procurement centres
- Farmer Producer Organisations (FPOs)
- Regulated markets
- Private traders
- Millet processing units
- Direct marketing
- Local consumer groups

Farmers should check the **current government procurement arrangements, quality requirements and applicable Minimum Support Price** before taking their produce to a procurement centre.

The basic principle is:

Good quality + proper drying + grading + the right market = better income.

Ten Steps Every Ragi Farmer Can Remember

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1. Choose a variety suitable for your soil and local climate.

2. Purchase good-quality, certified seed.

3. In Dharmapuri, plan nursery raising around August 15, depending on rainfall and soil moisture.

4. If mechanical transplanting is planned, prepare a proper mat nursery.

5. Transplant healthy seedlings at around 15–18 days of age.

6. Give special attention to weed management during the first 40 days.

7. Apply nutrients based on soil-test recommendations.

8. Irrigate according to soil moisture and important crop growth stages.

9. Harvest at the correct maturity stage and dry the grain properly.

10. Decide your marketing channel before harvest.

A Farmer's Success Should Become Another Farmer's Lesson

The purpose of sharing Mr. Mathaiyan's experience is not simply to highlight one farmer.

The real purpose is to show that **new ideas can be tested in farmers' own fields**.

Mat nursery, mechanical transplanting, farmyard manure, biofertilizers, mechanical weeding and careful irrigation are not separate ideas. When they are properly combined, they can become a practical and efficient crop-management system.

Agriculture improves when farmers **experiment, observe, learn and share their experiences**.

Conclusion

Ragi should no longer be viewed simply as a crop that depends entirely on rainfall.

Today, we have better varieties, improved nursery techniques, mechanical transplanting, soil testing, biofertilizers, improved water-management practices and better marketing opportunities.

The varieties discussed in this article each have different strengths:

Paiyur 2 – well suited to rainfed conditions in the Dharmapuri region.

ATL 1 – short duration, good yield potential and a strong stem.

GPU 28 – good resistance to blast disease.

GPU 67 – short plant type, less lodging and suitable plant structure.

ML 365 – good tillering ability, shorter duration and suitable for modern cultivation methods.

There is no single variety that is best for every farmer.

The right variety depends on:

- Soil type
- Rainfall
- Irrigation availability
- Disease history
- Crop duration
- Harvesting method
- Market demand

Farmers who want to try a new variety should first cultivate it on a small area of **10–20 cents** and compare it with their existing variety.

They should record the **yield, cultivation cost, disease incidence, water requirement, maturity period, grain quality and selling price**.

This simple practice will help farmers make better decisions in the following season.

Farming is not just about following a recommendation from a book. **True agricultural knowledge comes from trying, observing, learning and improving.**

Farmers like Mr. Mathaiyan, who are willing to try new methods in their own fields, can provide valuable lessons and confidence to other farmers.

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Today, we grow ragi.

Tomorrow, we should turn it into **healthy food, value-added products and better income for farmers**.

That is the path towards the future of ragi farming.

"Choose good seed.
Follow scientific cultivation.
Protect soil and water.
Produce quality ragi.
Find the right market."

***Let us grow ragi.*

Let us add value to ragi.

*Let us increase farmers' income.***

This can be the new path for the future of ragi farming in Dharmapuri.

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Wild small melon (*cucumis melo* var. *Agrestis*): an underutilized vegetable crop with high medicinal property

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Cucumis melo var. *agrestis*, commonly known as wild melon, is a wild variety of muskmelon belonging to the family Cucurbitaceae. It is an annual creeping or climbing herb that grows naturally in fields, roadsides, wastelands, and cultivated lands. The plant produces small, round fruits that are usually green with stripes and turn yellow when mature.

This wild melon is widely distributed in tropical and subtropical regions, including India. It is valued as an important genetic resource because it possesses natural resistance to several pests, diseases, and environmental stresses. Due to these traits, it is often used in breeding programs to improve cultivated melon varieties. In some regions, the young fruits are also consumed as vegetables or used in traditional medicine.

Botanical Description

- **Habit:** An annual, prostrate or climbing herbaceous vine with slender, hairy stems.
- **Root:** Well-developed taproot with numerous lateral roots.
- **Stem:** Green, angular, branched, hairy, and bears simple, unbranched tendrils at the nodes.
- **Leaves:** Simple, alternate, broad, orbicular to ovate, shallowly 3–5 lobed, rough and hairy, with long petioles.

- **Tendrils:** Simple, unbranched, arising from the leaf axils, helping the plant climb.
- **Flowers:** Yellow, unisexual, monoecious (male and female flowers borne on the same plant). Male flowers usually occur in clusters, while female flowers are mostly solitary.

- **Fruit:** Small, globose to oval berry (about 2–6 cm in diameter), green with light stripes when immature, turning yellow at maturity. The rind is thin, and the flesh is pale green to whitish.
- **Seeds:** Numerous, flat, oval, cream to pale yellow, smooth, and enclosed in a mucilaginous pulp.
- **Chromosome number:** 2n = 24.

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Agronomic Characteristics

- **Growth habit:** Annual, vigorous creeping or climbing vine with rapid vegetative growth.
- **Adaptability:** Well adapted to tropical and subtropical climates; grows naturally in cultivated fields, wastelands, roadsides, and field bunds.
- **Soil:** Performs well in well-drained sandy loam to loamy soils but can also tolerate poor soils.
- **Climate:** Prefers warm temperatures (25–35°C) and full sunlight.
- **Water requirement:** Moderately drought tolerant; requires less irrigation than cultivated melons.
- **Propagation:** Mainly propagated by seeds, with good germination under warm conditions.
- **Flowering and fruiting:** Early flowering with monoecious plants (male and female flowers on the same plant); produces many small fruits.
- **Pollination:** Primarily insect-pollinated, especially by bees.

- **Stress tolerance:** Exhibits tolerance to drought and certain abiotic stresses.
- **Pest and disease resistance:** Naturally resistant or tolerant to several pests and diseases, making it an important source of resistance genes in melon breeding.
- **Yield potential:** Produces numerous small fruits with abundant seed production.
- **Agronomic importance:** Used as a valuable genetic resource for crop improvement, especially for developing pest-, disease-, and stress-resistant muskmelon varieties.

Why is *Cucumis melo* var. *agrestis* Underutilized?

Cucumis melo var. *agrestis* is considered an underutilized crop because of the following reasons:

1. **Small fruit size** with low edible flesh compared to cultivated melons.
2. **Poor taste and quality**, often bitter or less sweet, reducing consumer preference.
3. **Lack of commercial cultivation**; it mainly grows as a wild or weedy species.
4. **Low market demand** due to limited awareness and preference for improved melon varieties.
5. **Limited research and breeding efforts** focused on its cultivation and improvement.
6. **Absence of standardized production practices** such as recommended varieties and crop management techniques.
7. **Poor post-harvest quality**, with fruits having a short shelf life and limited transportability.
8. **Low economic returns** for farmers compared to commercial cucurbit crops.
9. **Insufficient value addition and processing**, resulting in limited commercial use.
10. **Under-recognition of its genetic value**, although it is an important source of pest, disease, and drought resistance for melon breeding.

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Constraints in the Cultivation of *Cucumis melo* var. *agrestis*

1. **Small fruit size** with low edible pulp, reducing market value.
2. **Poor fruit quality**, including less sweetness or occasional bitterness.
3. **Low consumer acceptance** compared to cultivated muskmelon varieties.
4. **Lack of improved varieties** and certified quality seed.
5. **Limited commercial cultivation** and poor market demand.
6. **Inadequate production technologies** and agronomic recommendations.
7. **Short shelf life** and poor post-harvest handling characteristics.
8. **Low economic returns** discourage farmers from cultivating it.
9. **Susceptibility to yield losses** due to weeds, unfavorable weather, and poor crop management, despite its tolerance to some pests and diseases.
10. **Limited research, extension support, and awareness** regarding its cultivation and utilization.
11. **Lack of organized marketing and value addition**, restricting its commercial potential.
12. **Competition from improved melon cultivars**, which produce larger, sweeter, and more marketable fruits.

Future Scope of *Cucumis melo* var. *agrestis*

1. **Crop improvement:** Can be used as a valuable donor of genes for resistance to pests, diseases, drought, and heat stress in muskmelon breeding.
2. **Climate-resilient agriculture:** Its adaptability to harsh environments makes it useful for developing climate-resilient melon varieties.
3. **Conservation of germplasm:** Collection and conservation of its genetic diversity will support future breeding programs.
4. **Development of improved cultivars:** Breeding can improve fruit size, sweetness, yield, and market quality while retaining stress tolerance.
5. **Nutritional and medicinal research:** Further studies may identify beneficial phytochemicals and nutritional compounds for food and pharmaceutical uses.
6. **Value addition:** Processing into pickles, beverages, preserves, or functional food products can increase its economic value.
7. **Sustainable farming:** Its hardiness and lower input requirement make it suitable for low-input and organic farming systems.
8. **Seed production and breeding research:** It can be widely used as parental material in hybridization and genetic studies.
9. **Expansion of commercial cultivation:** With improved varieties and better market awareness, it has potential to become a niche crop.
10. **Farmer livelihood improvement:** Promoting its cultivation, processing, and marketing can provide additional income opportunities in dryland and marginal farming areas.

Research Needs of *Cucumis melo* var. *agrestis*

1. **Germplasm collection and conservation** to preserve its genetic diversity.
2. **Genetic characterization** using molecular markers to identify useful genes and traits.

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3. **Breeding programs** to develop high-yielding, better-quality, and stress-tolerant cultivars.
4. **Evaluation for pest and disease resistance** to identify resistant accessions for melon improvement.
5. **Studies on drought, heat, and salinity tolerance** to support climate-resilient crop development.
6. **Development of improved agronomic practices**, including optimum sowing time, spacing, irrigation, and nutrient management.
7. **Nutritional and phytochemical analysis** to determine its nutritional value and medicinal potential.
8. **Post-harvest studies** to improve shelf life, storage, packaging, and transportation.
9. **Value addition and processing research** for products such as pickles, beverages, preserves, and nutraceuticals.
10. **Seed production and propagation studies** to ensure quality seed availability.
11. **Economic and market research** to assess commercial feasibility and promote farmer adoption.
12. **Biotechnology and genomic studies** for gene mapping, marker-assisted selection, and development of improved muskmelon varieties.

Conclusion

Cucumis melo var. *agrestis* is an underutilized wild melon belonging to the family Cucurbitaceae with immense potential for sustainable agriculture. Although it is not widely cultivated due to its small fruits, low market demand, and limited commercial value, it serves as an important source of genes for resistance to pests, diseases, drought, and other environmental stresses. Conserving its genetic diversity and strengthening research on breeding, cultivation practices, and value addition can enhance its utilization. With continued scientific efforts, *Cucumis melo* var. *agrestis* can play a significant role in developing climate-resilient muskmelon varieties and improving future food and nutritional security.

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Enhancing Mustard Productivity through Improved Production Technology in Jehanabad

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- Name of Farmer: Shri Sachida Nand Prasad
- Father's/Husband's Name: Shri Ramchandra Prasad
- Village: Safepur Nonhi
- Block: Kako
- District: Jehanabad, Bihar – 804432
- Educational Qualification: XII
- Age : 58
- Farmers Categories (Marginal/Small/Big) : Small
- Major Farming System : Crop-based farming, with mustard as an important rabi crop

2. Background of the Farmer

Shri Sachida Nand Prasad, son of Shri Ramchandra Prasad, is a farmer from Safepur Nonhi village of Kako Block, Jehanabad district, Bihar. He owns approximately 8 acres of agricultural land, including 4 acres of medium land and 1 acre of lowland. Before coming in contact with Krishi Vigyan Kendra (KVK), Jehanabad, mustard cultivation was mainly based on conventional farmer practices. The farmer obtained a relatively low mustard productivity of only **9.59 q/ha**. The major constraints were excessive seed rate, broadcasting method of sowing, lack of seed and soil treatment, imbalanced fertilizer application, inadequate weed management and indiscriminate plant protection measures. Soil analysis showed available nitrogen of 256.2 kg/ha, phosphorus 35.5 kg/ha, potassium 180.0 kg/ha, pH 7.4 and organic carbon 0.54%, indicating the need for balanced nutrient management.

3. Association with Krishi Vigyan Kendra

Shri Sachida Nand Prasad came in contact with **Krishi Vigyan Kendra, Jehanabad**, for technical guidance on improving mustard productivity. Based on the constraints observed under conventional cultivation, KVK Jehanabad demonstrated an improved mustard production technology based on a high-yielding variety along with a complete package of recommended agronomic and plant protection practices.

The intervention focused on improving crop establishment, nutrient-use efficiency, weed management, plant protection and efficient water utilization. The farmer was provided technical guidance regarding the appropriate seed rate, improved sowing practices, seed treatment, soil treatment, balanced fertilizer application based on soil-test results, timely weed control and need-based plant protection.

The improved technology included **mustard variety RH 761**, seed treatment with *Trichoderma* and Thiamethoxam, soil application of *Trichoderma* with farmyard manure, three irrigations at critical growth stages, soil-test-based fertilizer application, pre-emergence weed management and need-based plant protection.

The intervention resulted in a substantial improvement in productivity and profitability compared with the farmer's earlier practice.

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4. Innovative Technology/Practice Adopted or Developed

The major innovation adopted by Shri Sachida Nand Prasad was the replacement of conventional mustard cultivation with an **improved production package based on the high-yielding variety RH 761** and scientifically recommended crop management practices.

The recommended seed rate was **5 kg/ha**, helping maintain an optimum plant population and reducing unnecessary expenditure on seed. The crop was established through line sowing/broadcasting followed by light planking, as mentioned in the demonstration record. Seed treatment was undertaken using **Trichoderma @ 20 g/kg seed and Thiamethoxam @ 5 g/kg seed**, while soil treatment consisted of **Trichoderma @ 2 kg/acre with farmyard manure**.

A major component of the technology was **soil-test-based nutrient management**. Based on the soil analysis, fertilizer application was planned at **80:40:40:20 kg/ha of N:P:K:S**, rather than relying on imbalanced fertilizer application. Weed management was carried out through pre-emergence application of **Pendimethalin @ 3 L/ha**.

For plant protection, the farmer adopted need-based measures, including **Azadiractin 300 ppm @ 5 ml/L water and Thiamethoxam 25 WG @ 0.5 g/L water**, as recorded in the demonstration.

Efficient water management was another important feature. Instead of excessive irrigation, **three irrigations were provided at critical crop stages**. This helped improve water-use efficiency while maintaining crop productivity.

The integrated package resulted in better crop establishment, optimum plant population, improved utilization of nutrients and soil moisture, healthier crop growth, better siliqua formation and improved seed filling. The combination of improved variety, balanced nutrition, seed and soil treatment, weed management, need-based plant protection and efficient irrigation represented a significant improvement over the farmer's earlier conventional practice.

5. Economic Impact

The adoption of improved mustard production technology resulted in a substantial improvement in productivity and economic returns. Under the farmer's conventional practice, mustard productivity was **9.59 q/ha**, whereas the demonstration using RH 761 and the improved production package achieved **17.36 q/ha**, representing an **81.0% increase in productivity**.

Although the cost of cultivation increased slightly from ₹27,000/ha to ₹28,000/ha, the increase in productivity resulted in substantially higher gross and net returns. Gross return increased from ₹74,375/ha under farmer practice to ₹1,01,838/ha under the demonstration. Net return increased from ₹47,375/ha to ₹73,838/ha.

The Benefit:Cost ratio also improved from **2.61 to 3.50**, demonstrating the economic advantage of adopting the improved technology.

Economic data

Particular	Before Intervention – Farmer Practice	After Intervention – Demonstration
Yield (q/ha)	9.59	17.36
Cost of Cultivation (₹/ha)	27,000	28,000
Gross Income/Return (₹/ha)	74,375	1,01,838
Net Income/Return (₹/ha)	47,375	73,838

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Benefit:Cost Ratio	2.61	3.50
Increase in Yield	—	81.0%
Increase in Gross Return	—	36.9%
Increase in Net Return	—	55.9%

6. Social Impact and Farmer-to-Farmer Extension

The success of the demonstration had a positive influence beyond the beneficiary farmer. Shri Sachida Nand Prasad expressed satisfaction with the performance of **RH 761** and the improved crop management practices. He observed healthier crop growth, better pod development, higher seed yield and significantly improved profitability compared with his earlier cultivation practices.

The successful demonstration also generated interest among neighbouring farmers. The performance of the improved variety and production package encouraged farmers in the surrounding area to consider adoption of RH 761 along with the recommended production practices.

The farmer has actively recommended the improved mustard variety and production technology to fellow farmers in his village and adjoining areas. Thus, the farmer has emerged as a local example of how scientific crop management can improve productivity and profitability.

A **Field Day at the crop maturity stage and Crop Cutting/Field Day** were also conducted as part of the demonstration activities. These events provided opportunities for farmers and KVK scientists to observe the performance of the technology under field conditions.

7. Entrepreneurship and Employment Generation

The available success-story record primarily documents the farmer's improvement in **mustard production and farm profitability** through adoption of improved production technology. The intervention increased mustard productivity from 9.59 q/ha to 17.36 q/ha and increased net return from ₹47,375/ha to ₹73,838/ha.

The improved production package has therefore strengthened the economic performance of the farmer's existing agricultural enterprise. Adoption of the high-yielding variety RH 761, optimum seed rate, balanced fertilizer application, improved plant protection and efficient irrigation enabled the farmer to obtain higher returns from the same cultivated area.

The farmer has decided to continue mustard cultivation using the improved technology and has encouraged fellow farmers to adopt the variety and production package

8. Awards, Recognition and Media Coverage

The successful performance of the demonstration encouraged neighbouring farmers to consider adoption of RH 761 and the associated improved production package.

9. Future Vision

Shri Sachida Nand Prasad intends to continue mustard cultivation using the improved production technology demonstrated by Krishi Vigyan Kendra, Jehanabad. He is satisfied with the performance of RH 761 and the improved package, particularly the better crop growth, pod development, seed yield and profitability obtained through scientific management.

The farmer's future vision is to maintain higher productivity through improved varieties, balanced nutrient management, efficient irrigation, timely weed management and need-based plant protection. He also intends to continue sharing his experience with fellow farmers in his village and adjoining areas so that the benefits of improved mustard production technology can be expanded across the mustard-growing areas of Jehanabad district.

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Field Day at the prematurity stage

Field Day and Crop Cutting

10. Message to Fellow Farmers

"I have experienced that scientific farming can make a significant difference in crop productivity and income. Earlier, my mustard productivity was only 9.59 q/ha, but after adopting the improved RH 761 variety and recommended production practices, I achieved 17.36 q/ha. I encourage fellow farmers to use quality seed, follow the recommended seed rate, undertake proper seed and soil treatment, apply fertilizers according to soil-test results, control weeds timely and use plant protection measures only when required. Proper irrigation at critical stages can also save water and maintain productivity. I thank KVK Jehanabad for providing technical guidance and encourage farmers to continuously learn and adopt improved technologies."

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From Field to Smartphone: How Mobile Apps Are Transforming Indian Agriculture

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Indian agriculture has travelled a remarkable journey over the past seven decades. The farmer of the 1960s depended largely on monsoon rainfall, traditional varieties, animal-drawn implements, locally available inputs and personal experience. Agricultural information moved slowly from research institutions to extension personnel and finally to farmers. Neighbours, input dealers, agricultural officers and personal experience were often the main sources of information. Today, the situation is dramatically different. A farmer can check tomorrow's weather before spraying a pesticide, photograph a diseased plant for preliminary diagnosis, calculate fertilizer requirements, check market prices, obtain information on crop insurance, access government schemes and communicate with agricultural experts all through a smartphone

This transformation is part of a much larger agricultural journey. Foodgrain production in India has increased from about 82 million tonnes in 1960-61 to an estimated 376.56 million tonnes in 2025-26. Rice, wheat and maize production have also reached unprecedented levels. Horticulture and oilseed production have expanded substantially over the years. This progress has been supported by agricultural research, improved varieties, irrigation, mechanization, fertilizers, plant-protection technologies, institutional credit, agricultural extension and better markets. But agriculture now faces a new challenge. The question is no longer simply "How can we produce more?" The farmer must increasingly ask When should I sow? How much fertilizer should I apply? Is this pest economically important? Will it rain after spraying? Which variety should I choose? Where can I obtain quality inputs? What is today's market price? Am I eligible for a government scheme? These are questions of timely, reliable and location-specific information. And this is where digital agriculture is creating a new revolution.

The Digital Agriculture Revolution

The Green Revolution brought improved seeds, irrigation and scientific inputs into the field. The emerging Digital Agriculture Revolution is bringing knowledge, data and decision-support tools into the farmer's hand. Today, smartphones can provide weather forecasts, crop advisories, pest and disease information, soil and fertilizer recommendations, market information, government services, insurance support, expert consultations and agricultural learning resources. In many ways, the smartphone is gradually becoming a digital agricultural extension centre in the palm of the hand. Earlier, agricultural knowledge generally moved in one direction Research Institution → Extension Worker → Farmer. Digital technology is shortening this chain. Today, information can reach farmers almost instantly, while farmers can simultaneously send photographs, field observations and questions back to experts. Extension is therefore becoming more interactive, responsive and demand-driven. The transformation can broadly be understood as Traditional Agriculture → Green Revolution Agriculture → Digital Agriculture. The emerging stage combines agricultural science with smartphones, mobile

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applications, artificial intelligence, satellites, drones, sensors, digital markets and real-time data. India's policy environment is also moving in this direction. The Digital Agriculture Mission, approved in 2024 with an outlay of ₹2,817 crore, seeks to strengthen the digital foundation of agriculture through components such as Agri Stack, the Krishi Decision Support System and digital soil-related information. The result is a new interface between agricultural science and the farmer is the mobile application.

From Weather to Markets: Apps Every Farmer Should Know

1. Weather and Climate Advisory

Meghdoot: Turning Weather Forecasts into Farm Decisions

Weather is one of the most important factors influencing agricultural decisions. Meghdoot, developed through collaboration among IMD, IITM and ICAR, provides weather forecasts and weather-based agricultural advisories. It provides district- and block-level forecasts, including information on rainfall, temperature, humidity and wind, along with agrometeorological advisories. The real strength of Meghdoot is that it attempts to translate weather information into farm decisions. Weather information can help farmers decide when to sow, irrigate, apply fertilizers, spray pesticides, undertake intercultural operations or harvest crops. The important message is simple, Meghdoot does not merely tell the farmer what the weather maybe it helps answer what the farmer should do because of that weather.

MAUSAM: Weather Intelligence at the Farmer's Fingertips

The **MAUSAM** application, developed by the India Meteorological Department, provides weather observations, forecasts and warnings. It includes hourly and extended forecast services and is available in multiple Indian languages. For farmers, such information can help in planning irrigation, sowing, spraying, harvesting and post-harvest operations. For example, if significant rainfall is expected, pesticide spraying may be postponed and harvesting can be planned more carefully. MAUSAM and Meghdoot can therefore complement each other: one provides weather intelligence, while the other helps translate weather into agricultural action.

DAMINI: Lightning Alerts for Farmer Safety

Agriculture often requires farmers and farm workers to work in open fields, making lightning a serious safety concern. DAMINI, developed by IITM, provides location-based lightning information and warnings along with precautionary measures. A timely warning can help farmers stop field operations, move to safer locations and protect livestock and farm workers. Technology, therefore, is not only about productivity it can also be about saving lives.

2. Crop Protection: From "Spray First" to "Detect First"

National Pest Surveillance System: AI for Pest Management

One of the most promising developments in digital crop protection is the National Pest Surveillance System (NPSS). The system uses artificial intelligence, machine learning and image-based technologies to support pest identification and surveillance. Government information cited in the source indicates that by July 2026, NPSS was being used by more than 10,000 extension workers and supported 73 crops and 436 pests. Its importance lies in encouraging a shift from routine pesticide application towards: Detect → Identify → Monitor → Decide → Manage. This supports Integrated Pest Management and more rational pesticide use. However, AI identification should not automatically be considered a final diagnosis. Pest population, crop stage, natural enemies and Economic Threshold Level must also be considered before management decisions are made.

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Plantix: A Digital Crop Doctor

Plantix demonstrates how image recognition and artificial intelligence can assist farmers in identifying crop-health problems. A farmer can photograph a damaged or diseased plant and receive a preliminary assessment. Its biggest advantage is speed. A farmer may obtain an initial diagnosis within minutes instead of waiting for an expert visit. But Plantix should be considered a diagnostic aid but not a replacement for an agricultural scientist. Image quality, crop stage, environmental conditions and similarities between symptoms can affect accuracy. Serious or uncertain cases, especially before pesticide application, should be confirmed with KVK scientists, agricultural officers or plant-protection specialists.

3. Soil, Fertilizer and Crop Production

Soil Health Card: Fertilization Based on Soil Testing

The **Soil Health Card** system helps farmers understand the nutrient status of their soil and obtain fertilizer recommendations based on soil testing. The system supports soil-sample registration, collection, testing and generation of soil-health information. Its broader objective is to encourage **"Right nutrient + Right quantity + Right time + Right place."** Soil-test-based nutrient management can help reduce unnecessary fertilizer expenditure while supporting long-term soil health. However, recommendations are only as reliable as the soil sample and interpretation. Proper soil sampling and crop-specific recommendations remain essential.

Farm Calculators and Fertilizer Calculator Goa

Digital farm calculators can simplify field-level calculations, including fertilizer requirements. Such tools can reduce calculation errors and make nutrient planning easier. The Fertilizer Calculator Goa, developed by ICAR–CCARI, represents a more crop- and soil-oriented approach to digital nutrient management. The larger significance of these tools is not simply calculating fertilizer quantities. It is the movement towards precision nutrient management.

Kisan Suvidha

Kisan Suvidha brings several farmer-oriented agricultural services into a digital environment, including information relating to weather, market prices, crop protection and agricultural inputs. Its importance lies in bringing multiple sources of farm information closer to farmers.

Kisan Rath

Agricultural production does not end at harvest. Produce must reach markets, warehouses, processing units or consumers. Kisan Rath was designed to facilitate transportation of agricultural and horticultural produce by connecting farmers, traders, transporters and other stakeholders. The platform became particularly important during the COVID-19 period, when movement of agricultural commodities faced major disruptions.

4. Markets and Marketing

e-NAM: Taking the Agricultural Market Digital

The **National Agriculture Market (e-NAM)** is one of India's major digital agricultural marketing initiatives. The e-NAM mobile platform provides facilities related to registration, lot information, auction progress and confirmation of sale price. Farmers can also track their traded lots through the market process. Its objectives include improving Price discovery, Transparency, Competition, Market access, Digital transactions. However, digital access does not automatically guarantee the highest price. Final price realization still depends on quality, grading, demand and supply, market conditions and transportation. The lesson is important Technology can improve market transparency, but quality produce and market fundamentals still matter.

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5. Crop Insurance and Risk Management

PMFBY Digital Services

Agriculture is inherently risky. Drought, floods, cyclones, pest outbreaks and other climatic events can cause major losses. The **Pradhan Mantri Fasal Bima Yojana (PMFBY)** has developed a digital ecosystem that includes the Farmer App, WhatsApp Chatbot, AIDE App, CCE App, CLAP and WINDS, among other services. These digital tools support crop-insurance application and management, crop-loss assessment, weather information and grievance-related services. Digital systems can make insurance services more accessible and transparent, but farmers should understand that claim settlement depends on notified crops and areas, policy conditions, insured risks and prescribed loss-assessment procedures.

6. Integrated Digital Platforms

DeHaat Kisan App

The **DeHaat Kisan App** brings together agricultural advisories, weather information, market-related services, crop recommendations, input access and government-scheme information. Its strength is integration, multiple services through one digital platform. However, farmers should compare input prices, product quality and market options before making commercial decisions.

IFFCO Kisan

IFFCO Kisan provides information related to weather, agriculture, market prices, satellite-based services and other agricultural information. Such platforms can complement conventional extension, but farmers should distinguish between general information, commercial product information and location-specific scientific recommendations.

7. AI Enters the Farmer's Pocket

Kisan e-Mitra: The AI Farming Assistant

Artificial intelligence is beginning to change the way farmers interact with agricultural information. **Kisan e-Mitra**, an AI-powered government chatbot, is designed to provide quick responses to agricultural queries. Such systems can help farmers obtain routine information without physically visiting an agricultural office. But AI-generated information should be treated as **decision-support information**, not unquestionable final advice. Pesticide selection, serious crop diseases, unusual symptoms and location-specific problems require expert validation.

BharatVistaar: One Digital Gateway for Agriculture

BharatVistaar represents the emerging generation of AI-enabled agricultural digital infrastructure. Its vision is to provide real-time, location-specific agricultural advisories while connecting farmers with government schemes and support services. According to government information cited in the source, by July 2026 BharatVistaar had served more than 3 lakh farmers and addressed more than 72 lakh farmer queries. Its larger vision is compelling, instead of asking farmers to search through many disconnected services, bring essential agricultural information together through one connected digital platform.

8. Kisan SARATHI 2.0: Bringing the Scientist Closer to the Farmer

From an agricultural-extension perspective, Kisan SARATHI 2.0 is particularly significant. The platform connects farmers with agricultural experts and advisory services. ICAR reported in March 2026 that more than 2.88 crore farmers had been registered on the Kisan SARATHI platform. The upgraded system includes features such as a three-tier calling system, help-desk functions, advisory dissemination, content creation and approval mechanisms, and location- and crop-specific advisories. Its importance for the KVK system is considerable. A farmer can increasingly communicate with agricultural experts without waiting for a physical visit. Thus, Kisan SARATHI 2.0 represents more than another mobile application. It represents the digital transformation of agricultural extension itself.

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9. Agri Stack: The Digital Backbone

Agri Stack is not simply another farmer app. It forms part of India's emerging digital agricultural infrastructure, including the Farmer Registry, Geo-Referenced Village Maps and Crop Sown Registry. These systems can connect information on farmers, land and crops with services such as schemes, credit, insurance and procurement. As reported in the source, more than 10.31 crore Farmer IDs had been created by 3 August 2026, while the Rabi 2025–26 Digital Crop Survey covered more than 31.3 crore plots across 648 districts. The significance of Agri Stack lies in its potential to make agricultural services increasingly data-enabled and targeted.

10. Bharat-VISTAAR: A New Digital Gateway for Smart and Resilient Agriculture

Bharat-VISTAAR (Value-Integrated System for Technology, Advisory and Agricultural Resilience) is an AI-powered digital agriculture platform developed by the Ministry of Agriculture & Farmers Welfare, Government of India, in collaboration with relevant agricultural and digital technology institutions. Launched in 2026, it aims to integrate weather information, market prices, soil health, pest surveillance, crop advisories and government schemes into a single platform. Through AI-enabled and voice-based services, farmers can seek timely, personalized information for better farm decisions. Bharat-VISTAAR marks an important shift from conventional information delivery towards interactive, data-driven and farmer-centric digital agricultural extension. These platforms highlight an important principle:

Digital agriculture becomes more useful when digital information is connected with local agricultural knowledge**.**

The Smartphone as a Digital Agricultural Extension Centre

Consider the journey of a farmer through one cropping season. Before sowing, the farmer may need information on weather, variety, seed rate and sowing time. During crop growth, the farmer may need fertilizer recommendations, irrigation advice and pest surveillance. At harvest, the farmer needs weather forecasts, market prices, transportation and post-harvest information. If crop failure occurs, insurance information becomes important. Earlier, these services were scattered across different institutions and physical locations. Today, a smartphone can increasingly connect many of these services. But this does not mean that every farmer needs dozens of apps. In fact, too many disconnected applications can create confusion. The future is not about more apps. It is about better integration. Platforms such as Agri Stack, Kisan SARATHI 2.0, BharatVistaar and integrated digital agricultural systems point towards this future.

The Changing Role of KVKs

The rise of agricultural apps does not make Krishi Vigyan Kendras less important. It makes them more important. A farmer may use Plantix for preliminary disease identification, Meghdoot for weather information, NPSS for pest surveillance and Kisan SARATHI 2.0 to contact an expert. But someone still needs to interpret all this information in the context of soil + crop + variety + crop stage + pest pressure + weather + local conditions. This is where KVKs can serve as the human bridge between digital technology and field reality. The extension scientist of tomorrow will not simply disseminate information. The scientist will increasingly become a Digital knowledge facilitator, Information validator, Technology guide, AI-advisory interpreter, Scientific-information filter, Link between farmers and digital platforms, The question for extension will therefore change from "How do I deliver information to farmers?" to "How do I help farmers identify, understand and use the right information?"

What Do Farmers Gain?

Agricultural mobile applications offer several important advantages by making farm information more timely, accessible, location-specific and

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actionable. Information can reach farmers much faster, reducing the need to travel to agricultural offices for routine queries. Weather forecasts and advisories can increasingly be tailored to specific locations, while access to information on weather, soil health, pests and diseases, market prices and crop insurance can help farmers make better-informed decisions. Digital platforms can also reduce the information gap between agricultural research institutions, extension personnel and farmers by bringing scientific knowledge closer to the field. Importantly, mobile applications enable two-way communication, allowing farmers to share photographs, ask questions and report field problems to experts. However, these benefits should not be overstated, as the actual impact of digital agriculture depends on factors such as internet connectivity, digital literacy, affordability, local-language availability, farmer trust and the quality and reliability of information.

The Other Side of the Smartphone

Every technological revolution brings its own challenges, and digital agriculture is no exception. One of the major concerns is the digital divide, as not every farmer has access to a smartphone, reliable internet connectivity or adequate digital skills. Language is another important issue; although many applications are now available in Indian and regional languages, the quality, accuracy and depth of information may differ. Farmers may also face information overload, receiving different or even conflicting recommendations from multiple digital sources. The growing use of Artificial Intelligence (AI) presents another challenge because AI can provide quick preliminary information, but its responses may not always be accurate, complete or suitable for a particular field situation. At the same time, digital agriculture generates valuable data related to farmers, land, crops and farming activities, making data privacy, cybersecurity and responsible data governance increasingly important. Farmers must also learn to distinguish science-based agricultural advice from commercial promotion, particularly when digital platforms combine advisory services with the sale of agricultural inputs. Therefore, the solution is not to reject technology, but to develop and promote trusted, farmer-friendly, scientifically validated and responsible digital agricultural technologies that complement, rather than replace, human expertise and agricultural extension services.

The Future: From Mobile Apps to Intelligent Agriculture

The next stage of digital agriculture is likely to move beyond individual mobile applications towards integrated intelligent agricultural platforms that can bring multiple sources of information together. Imagine a farmer asking, *"It is going to rain tomorrow, my paddy crop is at the flowering stage, and I am noticing brown planthoppers in one corner of my field. What should I do?"* A future digital agricultural assistant could combine weather data, crop growth stage, pest surveillance, soil information, satellite observations, field history and validated scientific knowledge to provide more location-specific and timely decision support. This represents a major shift from simply searching for information to receiving integrated decision support. Artificial intelligence, satellites, drones, sensors, Internet of Things (IoT) devices, digital crop surveys and farmer databases are increasingly creating opportunities for more connected and responsive agriculture. However, the objective should not be technology for technology's sake. The real goal is simple: the right information, at the right time, in the right language and in the right form, to support the right farm decision.

Conclusion: From Information to Insight

Indian agriculture has travelled a remarkable journey from the plough to the tractor, from traditional knowledge to scientific farming, from the Green Revolution to computers and the internet, and now from smartphones towards artificial

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intelligence. Although a smartphone is a small device, its potential to transform agricultural decision-making is enormous. Through mobile applications and digital platforms, farmers can access weather forecasts, soil information, crop advisories, pest and disease diagnosis, market prices, insurance services, government schemes and expert guidance at their fingertips. However, the success of digital agriculture should not be measured by the number of applications installed on a farmer's phone, but by whether these technologies lead to better decisions, reduced risks, improved productivity, greater profitability and a better quality of life. Farmers do not need dozens of disconnected applications; they need trusted, integrated, simple and farmer-friendly digital services.

Technology should also complement, not replace the farmer, scientist or extension worker. The future lies in technology with humans, combining the speed of digital intelligence with the practical judgement of field-based agricultural expertise. The extension worker of tomorrow will therefore evolve from an information disseminator into a digital guide, knowledge facilitator and information validator. The next agricultural revolution may not begin with a new machine entering the field; it may begin when a farmer opens a trusted digital platform before making an important farming decision. The smartphone is no longer merely a communication device it is becoming a gateway to agricultural knowledge and an intelligent companion in the farmer's journey from information to insight, from insight to decision, and from decision to better farm outcomes.

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CRISPR Based Crop Improvement for Sustainable Agriculture Recent Advances Challenges and Future Perspectives

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Global agriculture is facing unprecedented challenges due to climate change, population growth, diminishing natural resources, and the increasing incidence of pests and diseases. These challenges demand innovative breeding approaches capable of developing high yielding, climate-resilient, and nutritionally improved crop varieties within shorter timeframes. Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) and CRISPR-associated (Cas) proteins have emerged as transformative genome-editing tools that enable precise, efficient, and targeted modification of plant genomes. Unlike conventional breeding, which often requires several generations to introduce desirable traits, CRISPR technology allows breeders to directly modify genes associated with yield, stress tolerance, disease resistance, nutritional quality, and adaptation to changing environments. The application of CRISPR has been demonstrated successfully in several economically important crops, including rice, wheat, maize, soybean, tomato, potato, and cotton. Recent advances such as base editing, prime editing, multiplex genome editing, and DNA free genome editing have further expanded the scope of crop improvement while reducing unintended genetic changes. These technologies have accelerated the development of crop varieties capable of addressing food security and environmental sustainability. Despite its remarkable potential, several challenges remain, including efficient delivery systems, regulatory uncertainty, public acceptance, intellectual property concerns, and the possibility of off target mutations. Continued research, transparent regulation, and responsible implementation will be essential to maximize the benefits of CRISPR technology.

This article summarizes the principles of CRISPR-based genome editing, highlights its major applications in sustainable crop improvement, discusses current challenges, and outlines future opportunities for integrating CRISPR with genomics, artificial intelligence, and precision breeding to strengthen global food security.

1. Introduction

Agriculture has always been the foundation of human civilization, providing food, nutrition, livelihoods, and raw materials for growing populations. Today, however, agricultural production faces mounting pressure from rapid population growth, climate variability, land degradation, water scarcity, and the emergence of new pests and pathogens. According to projections by international organizations, global food production must increase substantially by 2050 to meet the nutritional demands of an expanding population while minimizing environmental impacts. Achieving this balance requires crop improvement strategies that are not only effective but also sustainable. For decades, conventional plant breeding has played a central role in increasing crop productivity through selection, hybridization, and mutation breeding. These methods have produced many successful cultivars but are often limited by long breeding cycles, dependence on naturally occurring genetic variation, and the difficulty of improving complex traits controlled by multiple genes. Although marker-assisted selection and genomic selection have accelerated breeding programs, the need for more precise and efficient technologies remains significant. Genome editing has transformed modern plant breeding by enabling targeted modifications of specific genes without altering the remainder of the genome. Among the available genome-editing technologies, CRISPR has

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become the most widely adopted because of its simplicity, versatility, high editing efficiency, and comparatively low cost. Adapted from the natural immune system of bacteria and archaea, the CRISPR-Cas system uses a guide RNA to direct the Cas enzyme to a selected DNA sequence, where precise genetic modifications can be introduced. This level of precision allows plant breeders to improve important agronomic traits while preserving the desirable genetic background of elite cultivars.

During the past decade, CRISPR technology has moved rapidly from laboratory research to practical applications in agriculture. Researchers have successfully edited genes associated with grain yield, flowering time, plant architecture, nutrient-use efficiency, resistance to fungal, bacterial, and viral diseases, tolerance to drought and salinity, and enhanced nutritional quality. In rice, targeted editing of yield- and stress-related genes has improved productivity under adverse environmental conditions. In wheat, CRISPR has been used to enhance resistance to fungal diseases and improve grain quality. Similar progress has been reported in maize, soybean, tomato, potato, and several horticultural crops, highlighting the broad applicability of this technology across diverse plant species. The emergence of advanced genome-editing approaches, including base editing and prime editing, has further increased the precision of genetic modifications by enabling single-nucleotide substitutions or targeted sequence changes without creating double-stranded DNA breaks. These innovations reduce the likelihood of unintended genetic alterations and expand the range of traits that can be improved through genome editing. At the same time, integrating CRISPR with genomic selection, speed breeding, high-throughput phenotyping, and artificial intelligence is creating new opportunities for accelerating genetic gain in crop improvement programs.

Although CRISPR technology offers tremendous promise, its widespread adoption depends on addressing technical, regulatory, ethical, and societal challenges. Efficient delivery methods, comprehensive biosafety assessments, harmonized regulatory frameworks, and public awareness will be critical for ensuring the responsible use of genome-edited crops. As scientific knowledge and regulatory policies continue to evolve, CRISPR-based breeding is expected to become a cornerstone of sustainable agriculture, contributing to resilient cropping systems, improved resource-use efficiency, and long-term food and nutritional security.

This article examines recent advances in CRISPR-based crop improvement, explores its contributions to sustainable agriculture, discusses current limitations, and highlights future research directions for developing resilient and productive crop varieties capable of meeting global agricultural challenges.

2. CRISPR Technology: Principles and Mechanism of Genome Editing

The development of CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) technology has revolutionized plant breeding by providing a fast, accurate, and cost-effective method for modifying plant genomes. Originally discovered as a natural adaptive immune system in bacteria and archaea, CRISPR enables these microorganisms to recognize and destroy invading viruses. Scientists adapted this natural defense mechanism into a powerful genome-editing tool capable of introducing precise genetic changes in plants, animals, and microorganisms. The CRISPR-Cas system functions through two key components: a guide RNA (gRNA) and a CRISPR associated (Cas) protein. The guide RNA is designed to recognize a specific DNA sequence within the plant genome, while the Cas protein acts as molecular scissors that cut the DNA at the targeted location. Once the DNA is cleaved, the plant's natural repair mechanisms become active. During this repair process, small insertions, deletions, or precise sequence modifications can be introduced, allowing researchers to knock out undesirable genes, modify existing genes, or insert beneficial genetic changes.

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Among the different CRISPR systems, CRISPR-Cas9 remains the most widely used because of its high editing efficiency and ease of design. Cas9 has been successfully employed in numerous crop species, including rice, wheat, maize, soybean, tomato, and cotton, to improve yield, disease resistance, stress tolerance, and grain quality. Its versatility has made it the preferred genome-editing platform in many crop improvement programs.

Recent years have witnessed the development of several advanced CRISPR systems that extend the capabilities of genome editing. Cas12 (Cpf1) differs from Cas9 in its DNA recognition pattern and produces staggered DNA cuts, making it particularly useful for editing specific genomic regions. Cas13 targets RNA rather than DNA, providing new opportunities for controlling RNA viruses and regulating gene expression without permanently altering the genome. These innovations have significantly expanded the applications of CRISPR in agricultural research.

Another important breakthrough is the development of base editing, which enables scientists to change a single DNA base without generating double-stranded DNA breaks. This approach is especially valuable for correcting naturally occurring mutations or introducing beneficial alleles responsible for improved agronomic traits. Base editing minimizes unwanted genetic alterations and enhances editing precision, making it an attractive strategy for modern plant breeding.An equally promising advancement is prime editing, often described as a "search-and-replace" genome-editing technology. Prime editing combines a modified Cas protein with reverse transcriptase and a specially designed guide RNA to introduce targeted insertions, deletions, or substitutions without requiring donor DNA templates. This technology offers greater flexibility and accuracy than conventional CRISPR approaches and has enormous potential for improving complex traits controlled by multiple genes. Modern breeding programs are also utilizing multiplex genome editing, where multiple genes are edited simultaneously within a single experiment. Since many important agricultural traits such as drought tolerance, yield potential, nutrient-use efficiency, and disease resistance are governed by several interacting genes, multiplex editing allows breeders to improve these complex traits more efficiently than traditional breeding methods.

Delivering CRISPR components into plant cells remains a critical step in successful genome editing. Common delivery methods include *Agrobacterium tumefaciens*-mediated transformation, particle bombardment (gene gun), polyethylene glycol-mediated transformation of protoplasts, and ribonucleoprotein (RNP)-based delivery. More recently, DNA-free genome editing using CRISPR ribonucleoproteins has gained attention because it avoids stable integration of foreign DNA into the plant genome. This approach may simplify regulatory approval in several countries and improve public acceptance of genome-edited crops. Compared with conventional breeding and earlier genome-editing technologies such as zinc finger nucleases (ZFNs) and transcription activator-like effector nucleases (TALENs), CRISPR offers several distinct advantages. It is relatively inexpensive, easy to design, highly efficient, and capable of editing multiple genes simultaneously. These characteristics have accelerated crop improvement programs worldwide and enabled researchers to address agricultural challenges that were previously difficult to solve. As genome editing technologies continue to evolve, CRISPR is increasingly being integrated with genomics, transcriptomics, high throughput phenotyping, artificial intelligence, and speed breeding. This multidisciplinary approach is expected to shorten breeding cycles, improve selection accuracy, and facilitate the development of climate-resilient, high yielding, and nutritionally superior crop varieties. Consequently, CRISPR has become one of the most influential innovations in contemporary plant breeding and is poised to play a

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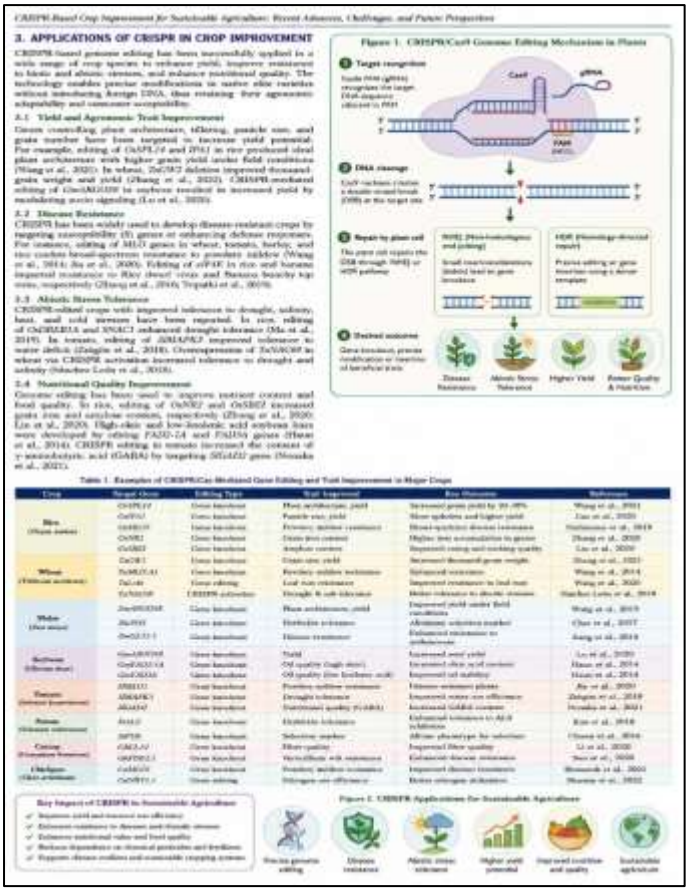
central role in achieving sustainable agricultural production in the coming decades.

Figure :1



3. Applications of CRISPR in Crop Improvement for Sustainable Agriculture

In India, application of CRISPR technology has transformed crop improvement by enabling plant breeders to modify genes associated with economically important traits with remarkable precision. Unlike conventional breeding, where the transfer of desirable traits may require several generations and often introduces unwanted genetic material, CRISPR allows targeted editing of specific genes while preserving the superior genetic background of elite cultivars. Consequently, genome editing has become an indispensable tool for developing climate-resilient, high-yielding, disease-resistant, and nutritionally enhanced crop varieties that support sustainable agricultural production.

3.1 Yield Enhancement and Agronomic Improvement

Increasing crop productivity remains one of the primary objectives of plant breeding. CRISPR technology has enabled researchers to manipulate genes regulating plant architecture, flowering time, tillering, grain size, seed weight, and biomass production.

In rice (*Oryza sativa*), targeted editing of OsSPL14, IPA1, and Gn1(Table 1) has significantly improved grain number, panicle architecture, and overall yield potential. Similarly, knockout of the TaGW2 gene in wheat resulted in larger grain size and higher thousand-grain weight. In maize and soybean, editing genes associated with plant growth and carbon allocation has contributed to increased biomass accumulation and improved harvest index. These improvements demonstrate that genome editing can substantially accelerate genetic gain while reducing the breeding cycle, making it an effective strategy for meeting future food demands.

India has begun advancing CRISPR edited crops, but very few have been officially released for commercial cultivation.

Table :1 List of CRISPR developed varieties remain in research, confined field trials, or are awaiting regulatory approval.

Crop	Variety/Line	Target Trait	Institution	Status
Rice (*Oryza sativa*)	Improved Samba Mahsuri, Pusa Basmati (edited lines)	Bacterial blight resistance, yield, grain quality	IIRR-Indian Institute of Rice Research, Hyderabad	Experimental

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Rice	CRISPR-edited drought-tolerant rice	Drought tolerance	IIRR- Indian Institute of Rice Research	Field evaluation
Tomato (*Solanum lycopersicum*)	CRISPR tomato lines	Shelf life, fruit quality	IIVR-Indian Institute of Vegetable Research, Varanasi (U.P)	Research stage
Banana (*Musa spp.*)	CRISPR banana	Fusarium wilt resistance	NRCB-National Research Centre for Banana, Trichy, (Tiruchirappalli) TN.	Experimental
Wheat (*Triticum aestivum*)	CRISPR wheat lines	Rust resistance, grain quality	IIWBR-Indian Institute of Wheat and Barley Research, Karnal, (HR)	Research stage
Mustard (*Brassica juncea*)	Edited mustard	Improved oil quality	IARI-Indian Agricultural Research Institute, New Delhi	Research stage
Chickpea (*Cicer arietinum*)	CRISPR chickpea	Drought tolerance, disease resistance	IIPR-Indian Institute of Pulses Research, Kanpur (U.P.)	Research stage

Source: https://www.icar.gov.in/en/recent-research-initiatives?utm

3.2 Development of Disease Resistant Crops

Plant diseases account for considerable annual losses in global agricultural production. CRISPR has emerged as a sustainable alternative to excessive pesticide use by enabling precise modification of disease susceptibility genes and enhancement of natural plant defence mechanisms. One of the most successful examples involves the MLO gene, where gene knockout has conferred durable resistance to powdery mildew in wheat, barley, tomato, and several other crops. Likewise, editing the eIF4E gene has generated resistance against important viral diseases in rice, cucumber, cassava, and banana. CRISPR has also been employed to improve resistance against bacterial blight, bacterial leaf streak, blast disease, and fungal pathogens by modifying host-pathogen interaction pathways.

Such disease resistant varieties reduce dependence on chemical fungicides and insecticides, thereby lowering production costs while minimizing environmental contamination.

3.3 Improving Tolerance to Abiotic Stresses

Climate change has intensified the occurrence of drought, salinity, heat, cold, and flooding, threatening agricultural productivity worldwide. CRISPR-based genome editing offers a rapid approach for developing stress-resilient crop varieties capable of maintaining productivity under adverse environmental conditions.

Editing drought-responsive genes such as OsDREB1A, SNAC1, and AREB has enhanced water-use efficiency and drought tolerance in rice. In tomato, modification of SlMAPK3 improved

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tolerance to water deficit, while editing stress-responsive genes in soybean increased resistance to salinity. Similar improvements have been reported in maize and wheat, where edited plants exhibited enhanced antioxidant activity, better root development, and improved physiological adaptation under environmental stress. The development of climate resilient cultivars through genome editing contributes directly to sustainable agricultural systems by ensuring stable crop production despite increasingly unpredictable climatic conditions.

3.4 Nutritional Quality Improvement

Beyond increasing productivity, modern breeding aims to improve the nutritional value of staple food crops. CRISPR technology provides a precise method for enhancing essential nutrients while maintaining desirable agronomic characteristics.

Researchers have successfully increased iron and zinc accumulation in rice by editing nutrient transport genes. Similarly, modification of starch biosynthesis genes has improved cooking quality and grain texture. In soybean, editing the FAD2 gene increased oleic acid content while reducing undesirable polyunsaturated fatty acids, thereby improving oil stability and nutritional value. In tomato, CRISPR mediated modification of the SlGAD2 gene enhanced gamma-aminobutyric acid (GABA) concentration, producing fruits with added health benefits.

These examples illustrate how genome editing can simultaneously address food security and nutritional security, supporting the development of healthier diets without compromising agricultural productivity.

3.5 Sustainable Weed and Pest Management

CRISPR has also opened new opportunities for integrated pest and weed management. Researchers are exploring genome editing to improve herbicide tolerance, insect resistance, and pest management strategies while reducing reliance on synthetic agrochemicals.

Editing susceptibility genes involved in insect-plant interactions has improved resistance against several economically important pests. Furthermore, gene-editing approaches targeting weed biology may contribute to more efficient weed control in the future. These innovations support environmentally friendly crop production by decreasing pesticide application and preserving biodiversity within agricultural ecosystems.

Table 2. Representative Applications of CRISPR in Major Crop Species

Crop	Target Gene	Trait Improved	Major Outcome
Rice	OsSPL14	Grain yield	Improved panicle architecture and yield
Rice	OsNR2	Nitrogen use efficiency	Reduced fertilizer requirement
Wheat	TaGW2	Grain size	Increased thousand-grain weight
Wheat	MLO	Powdery mildew resistance	Durable disease resistance
Maize	ARGOS8	Drought tolerance	Improved productivity under water deficit
Soybean	FAD2	Oil quality	Increased oleic acid content
Tomato	SlMAPK3	Drought tolerance	Better water-use efficiency

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Tomato	SlGAD2	Nutritional quality	Enhanced GABA concentration
Potato	ALS	Herbicide tolerance	Improved weed management
Cotton	GhCLA1	Fibre quality	Enhanced fibre characteristics

Key Contributions of CRISPR to Sustainable Agriculture

- Accelerates crop improvement by reducing breeding time.
- Enables precise modification of elite cultivars without introducing undesirable traits.
- Enhances yield potential and resource-use efficiency.
- Improves resistance to insects, fungi, bacteria, and viruses.
- Develops crops tolerant to drought, salinity, heat, and other climate-related stresses.
- Improves nutritional quality and food safety.
- Reduces dependence on pesticides, fertilizers, and other agrochemicals.
- Supports environmentally sustainable and climate-smart agricultural systems.

Overall, CRISPR-based genome editing represents a paradigm shift in plant breeding. By integrating precision genetics with conventional breeding strategies, researchers can develop crop varieties that are more productive, resilient, and environmentally sustainable. As new genome-editing technologies continue to evolve, CRISPR is expected to play an increasingly important role in ensuring global food and nutritional security under changing climatic conditions.

CRISPR-edited crop approved in India

As of 2026, India has not officially released a CRISPR-edited crop variety for large-scale commercial cultivation under the national variety release system. However:

- In 2022, the Government of India exempted certain SDN-1 and SDN-2 genome-edited plants (those without foreign DNA insertion) from parts of the GMO regulatory framework, making research and commercialization pathways easier.
- Several ICAR institutes, agricultural universities, and biotechnology organizations are conducting advanced field evaluations of CRISPR-edited rice, wheat, tomato, banana, chickpea, mustard, and other crops.
- Commercial releases are expected in the coming years as candidates' complete biosafety and varietal evaluation requirements.

4. Challenges, Biosafety, Regulatory Framework, and Future Perspectives

Although CRISPR technology has revolutionized plant breeding by enabling precise and efficient genome editing, several scientific, technical, regulatory, and social challenges continue to influence its widespread adoption. Addressing these issues is essential for translating laboratory discoveries into commercially successful crop varieties that contribute to sustainable agriculture and global food security.

4.1 Technical Challenges in CRISPR-Based Crop Improvement

Despite remarkable progress, genome editing is not free from limitations. One of the primary concerns is off-target editing, where unintended DNA sequences may be modified due to partial similarity with the designed guide RNA. Although the frequency of off-target mutations has been significantly reduced through improved guide RNA design, high-fidelity

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Cas proteins, and advanced bioinformatics tools, continuous validation remains necessary before commercial release.

Another challenge is the efficient delivery of CRISPR components into plant cells. While *Agrobacterium tumefaciens*-mediated transformation and particle bombardment are commonly used, many economically important crops and elite breeding lines remain difficult to transform and regenerate. Developing genotype-independent transformation methods is therefore an active area of research. Many important agronomic traits, including grain yield, drought tolerance, nutrient-use efficiency, and climate resilience, are controlled by multiple interacting genes. Editing a single gene often produces only modest improvements. Consequently, future breeding programs will increasingly rely on multiplex genome editing, where several genes are modified simultaneously to achieve greater genetic gains.

4.2 Biosafety and Environmental Considerations

Genome edited crops have generated considerable discussion regarding biosafety and ecological sustainability. Unlike traditional transgenic crops, many CRISPR-edited plants do not contain foreign DNA after the editing process, particularly when DNA-free editing systems are employed. This characteristic has prompted scientists to argue that certain genome-edited crops resemble naturally occurring mutations or conventionally bred varieties.

Nevertheless, comprehensive biosafety evaluations remain essential before field release. Researchers must assess potential unintended effects on plant metabolism, interactions with beneficial organisms, biodiversity, and long-term ecosystem stability. Transparent scientific evaluation and continuous post-release monitoring will help ensure responsible deployment of genome-edited crops. Importantly, CRISPR technology also supports environmental sustainability by reducing dependence on synthetic pesticides, fungicides, and chemical fertilizers. Disease-resistant and stress-tolerant crop varieties can lower agricultural inputs, improve resource-use efficiency, and reduce greenhouse gas emissions associated with intensive farming practices.

4.3 Regulatory Framework Across the World

The regulation of genome-edited crops varies considerably among countries. Several nations evaluate genome-edited plants according to the characteristics of the final product rather than the breeding method used to develop them. In contrast, some countries regulate genome-edited crops under frameworks similar to those applied to genetically modified organisms (GMOs).

Countries such as the United States, Japan, Argentina, Brazil, and Australia have adopted relatively flexible regulatory approaches for certain genome-edited crops that do not contain foreign DNA. These policies have encouraged innovation and accelerated commercialization. Conversely, regulatory processes in some regions remain more stringent, resulting in longer approval timelines. India has also taken important steps toward developing an enabling regulatory environment for genome editing. Recent policy updates have distinguished selected genome-editing approaches from conventional transgenic technologies, creating new opportunities for agricultural research while maintaining biosafety oversight.

International harmonization of regulatory policies will be crucial for facilitating global trade, encouraging innovation, and ensuring public confidence in genome-edited agricultural products.

Table 3. Regulatory Status of Genome-Edited Crops in Selected Countries

Country	Regulatory Approach	Current Status
India	Gene-editing guidelines introduced	Regulatory pathway evolving

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United States	Product-based	Several genome-edited crops approved
Japan	Product-based	Commercial cultivation permitted for selected crops
Argentina	Case-by-case assessment	Supportive regulatory framework
Brazil	Product based	Rapid approval pathway available
Australia	Relaxed regulation for SDN-1 edits	Research and commercialization progressing
European Union	Process-based (under revision)	Policy discussions ongoing

4.4 Ethical and Societal Considerations

The long-term success of CRISPR technology depends not only on scientific advancements but also on public trust. Transparent communication regarding the benefits, risks, and limitations of genome editing is essential to address misconceptions and improve consumer acceptance. Ethical considerations include equitable access to genome-editing technologies, intellectual property rights, affordability for smallholder farmers, and protection of indigenous crop genetic resources. Public-private partnerships, responsible innovation, and science-based policymaking will play important roles in ensuring that the benefits of CRISPR are shared broadly across society.

4.5 Future Perspectives

The future of CRISPR-based crop improvement is exceptionally promising. Recent developments in base editing, prime editing, epigenome editing, and DNA-free genome editing are enabling increasingly precise genetic modifications while minimizing unintended changes. The integration of CRISPR with artificial intelligence (AI), genomic selection, speed breeding, high-throughput phenotyping, remote sensing, and digital agriculture is expected to transform plant breeding into a faster, more predictive, and data-driven discipline. AI-assisted identification of candidate genes, combined with rapid genome editing and accelerated breeding cycles, will significantly shorten the time required to develop superior crop varieties.

Future research is also expected to focus on de novo domestication of wild crop relatives, improvement of orphan crops, enhancement of photosynthetic efficiency, biological nitrogen fixation, carbon sequestration, and breeding for climate resilience. These innovations will contribute directly to achieving the United Nations Sustainable Development Goals by improving food security, reducing environmental impacts, and strengthening agricultural resilience.

Overall, CRISPR technology is evolving from a powerful research tool into an essential component of modern crop improvement programs. With continued scientific innovation, effective regulatory frameworks, and responsible implementation, genome editing has the potential to reshape global agriculture and support sustainable food production for future generations.

Major Indian institutes working on CRISPR crop improvement

- Indian Council of Agricultural Research (ICAR)
- Indian Agricultural Research Institute (IARI)
- Indian Institute of Rice Research (IIRR)
- Indian Institute of Wheat and Barley Research (IIWBR)
- Indian Institute of Pulses Research (IIPR)
- National Research Centre for Banana (NRCB)
- Indian Institute of Vegetable Research (IIVR)

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Conclusion

CRISPR-based genome editing has emerged as one of the most transformative innovations in modern plant breeding, offering precise, efficient, and rapid improvement of economically important crop traits. Its successful application in enhancing yield, nutritional quality, disease resistance, and tolerance to abiotic stresses demonstrates its immense potential to support sustainable agriculture and global food security. Advanced technologies such as base editing, prime editing, and multiplex genome editing have further increased the accuracy and versatility of crop improvement. However, challenges related to efficient gene delivery, off target effects, regulatory policies, biosafety, and public acceptance must be addressed to enable wider adoption. Future progress will depend on integrating CRISPR with genomics, artificial intelligence, speed breeding, and precision agriculture to accelerate the development of climate-resilient and resource-efficient crop varieties. With continued scientific innovation, responsible regulation, and collaborative research, CRISPR has the potential to reshape global agriculture and contribute significantly to sustainable food production for future generations.

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Mandya's Agricultural Transformation: From Traditional Farming To Technology-Driven Agriculture

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Agriculture has historically been the foundation of Mandya district's economy and rural society. The agricultural landscape of Mandya has undergone substantial transformation from traditional, labour-intensive farming towards increasingly irrigated, mechanised, digitally supported and diversified agricultural production.

Irrigation development, particularly following the construction of the Krishnaraja Sagara (KRS) reservoir, significantly altered cropping patterns and agricultural productivity. Today, farmers increasingly use tractors, harvesters, improved irrigation systems, mobile-based agricultural information, scientific crop-management practices and other technologies.

At the same time, the district faces challenges including water dependence, rising cultivation costs, labour shortages, climate variability, soil degradation and fluctuations in agricultural markets. This paper analytically examines the major dimensions of agricultural transformation in Mandya, focusing on irrigation, mechanisation, digital agriculture, crop diversification and sustainable farming.

The study uses secondary information from government departments, official agricultural databases and ICAR publications. The analysis suggests that technology has created new opportunities for improving productivity and resource efficiency, but long-term agricultural sustainability requires integrated water management, appropriate mechanisation, diversified cropping systems, digital extension services and environmentally responsible farming practices.

1. Introduction

Agriculture occupies a central position in the economic and social structure of Mandya district in Karnataka. The district has traditionally been associated with irrigated agriculture, particularly paddy and sugarcane cultivation, along with coconut, sericulture and other crops. The Government of Karnataka describes Mandya as one of the agriculturally prosperous districts of the state and notes that irrigation from the K.R. Sagar reservoir during the 1930s produced a substantial transformation in cropping patterns, crop composition and yield levels.

Mandya has a geographical area of approximately 4.98 lakh hectares, while the official district agriculture page reports about 2.49 lakh hectares as sown area. The same source reports approximately 1.17 lakh hectares of irrigated area, with K.R. Sagar accounting for about 88,000 hectares and the Hemavathi reservoir for approximately 16,000 hectares. Tanks, wells and borewells provide irrigation to other agricultural areas.

The development of irrigation changed agriculture from predominantly rainfall-dependent cultivation into a more assured production system. Irrigation encouraged farmers to adopt water-intensive commercial crops and improved varieties, while also facilitating multiple cropping and greater agricultural investment. However, agricultural transformation is no longer limited to irrigation. Mechanisation, digital advisory systems, improved seeds, precision agriculture, crop diversification and sustainable

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natural-resource management are increasingly important.

The present transformation can therefore be understood as a transition from traditional agriculture towards a technology-supported agricultural system. This transition has economic, social and environmental implications for farmers and rural communities.

2. Objectives of the Study

The major objectives of this research paper are:

1. To examine the transformation of agriculture in Mandya district.
2. To analyse the role of irrigation in changing agricultural production.
3. To examine the growth and importance of farm mechanisation.
4. To assess the emerging role of digital agriculture and ICT-based extension services.
5. To examine crop diversification and changing agricultural practices.
6. To analyse sustainable farming practices and resource-management challenges.
7. To identify major challenges and suggest measures for strengthening technology-driven agriculture in Mandya.

3. Methodology

The study is based primarily on secondary data and documentary analysis. Information has been collected from official Government of Karnataka sources, the Mandya District Administration, the Karnataka Open Government Data platform, the Directorate of Economics and Statistics, the Ministry of Agriculture and Farmers Welfare, and the Indian Council of Agricultural Research (ICAR).

The Karnataka Open Government Data platform provides district-wise and season-wise information on crop area and production, while the Mandya crop survey database provides detailed crop information at village, hobli and taluk levels. These datasets provide an important basis for analysing changes in cropping patterns and agricultural production.

The research adopts a descriptive and analytical approach. Rather than relying only on production statistics, the study considers the interaction between irrigation, technology, labour, cropping patterns, digital information and sustainability.

4. Transformation through Irrigation

Irrigation has been the most important historical factor in the transformation of Mandya agriculture. The construction and development of the K.R. Sagar irrigation system created an important foundation for agricultural intensification. According to the Mandya District Administration, irrigation from K.R. Sagar during the 1930s substantially changed cropping patterns and improved yield levels and economic conditions.

The district's agricultural development is closely associated with the waters of the Cauvery and Hemavathi systems. Official district information indicates that approximately 48 percent of agricultural land is irrigated, while the remaining area has a more limited irrigation base and is relatively dependent on rainfall.

Irrigation encouraged the expansion of paddy and sugarcane and supported commercial agriculture. Irrigated agriculture also created conditions for farmers to invest in improved seeds, fertilisers, farm machinery and other agricultural inputs.

However, irrigation dependence creates challenges. Water availability is influenced by rainfall, reservoir storage, river flows and competing demands. Consequently, agricultural sustainability requires greater emphasis on water-use efficiency. Micro-irrigation, farm ponds, water harvesting and improved irrigation scheduling can reduce pressure on water resources.

The transformation of Mandya therefore demonstrates that irrigation can increase agricultural

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opportunities, but assured irrigation alone cannot guarantee long-term sustainability. Water must be managed as a limited economic and ecological resource.

5. Agricultural Mechanisation

Mechanisation represents another major stage in Mandya's agricultural transformation. Traditional agriculture depended heavily on human and animal labour for land preparation, sowing, weeding, harvesting and threshing. Increasing labour costs and shortages have encouraged farmers to adopt tractors, power tillers, pumps, harvesters, threshers and other agricultural machinery.

Mechanisation can reduce the time required for agricultural operations and can help farmers complete operations within appropriate crop-management windows. It can also reduce physical drudgery and dependence on manual labour.

At the state level, Karnataka has implemented programmes such as the Sub-Mission on Agricultural Mechanization (SMAM) and Krishi Yantra Dhare, which provide access to machinery and custom-hiring services. A recent Karnataka government research report notes that Krishi Yantra Dhare custom-hiring centres have been implemented to provide farm machinery to small and marginal farmers at nominal hiring charges.

Custom hiring is particularly relevant for small farmers because purchasing expensive machinery individually may not be economically feasible. Shared machinery services allow farmers to obtain mechanisation benefits without bearing the entire capital cost.

The next stage of mechanisation is increasingly connected with precision agriculture, automation, sensors, drones and data-based decision-making. ICAR identifies artificial intelligence, robotics, automation and the Internet of Things among important areas for future agricultural mechanisation.

Thus, mechanisation in Mandya should not simply mean greater use of tractors. It should involve appropriate, affordable and crop-specific technologies that improve productivity while reducing unnecessary expenditure.

6. Digital Agriculture and Agricultural Information

Digital technology is creating another important dimension of agricultural transformation. Farmers increasingly obtain information through mobile phones, digital platforms, weather services, online markets and agricultural advisory systems.

Digital agriculture can support farmers in several areas:

- weather-based decision-making;
- pest and disease identification;
- crop planning;
- market-price information;
- access to government schemes;
- soil and nutrient management;
- irrigation decisions; and
- improved communication with agricultural experts.

ICAR's agricultural extension system increasingly uses ICT and digital platforms to provide farm advisories. The Kisan Sarathi platform, for example, provides a digital interface connecting farmers with agricultural experts and advisory services.

Mandya also has a Krishi Vigyan Kendra, and ICAR's 2026 directory identifies the Mandya KVK and its institutional contact details. KVKs play an important role in technology assessment, demonstrations, farmer training and agricultural advisory services.

Digital agriculture therefore has the potential to reduce the information gap between farmers and agricultural institutions. However, digital adoption is not automatic. Differences in age, education, digital

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literacy, internet access and language can influence farmers' ability to use digital services effectively.

Consequently, digital agriculture should complement rather than replace physical agricultural extension. Local demonstrations, farmer training and direct interaction with agricultural experts remain important.

7. Crop Diversification

Crop diversification is an important component of agricultural transformation. Traditional agricultural systems in Mandya have developed around major irrigated crops such as paddy and sugarcane, while coconut, sericulture, horticultural crops and other enterprises also contribute to agricultural livelihoods. The district administration specifically identifies paddy, sugarcane, coconut and sericulture among important agricultural activities.

Diversification can reduce farmers' dependence on a single crop and may improve income stability. It can involve:

1. shifting part of the cultivated area to alternative crops;
2. integrating horticulture into farming systems;
3. combining crops with dairy or livestock;
4. developing value-added agricultural products;
5. adopting less water-intensive crops where appropriate; and
6. strengthening farm-based enterprises.

ICAR has emphasised crop diversification, integrated farming systems and resource-management approaches as important strategies for improving agricultural sustainability.

Nevertheless, diversification depends on market demand, irrigation availability, price stability, technical knowledge, storage facilities and processing infrastructure. Farmers may be reluctant to shift from established crops if alternative markets are uncertain.

Therefore, crop diversification must be supported by market linkages, processing, storage, extension services and reliable price information.

8. Sustainable Farming Practices

Technological transformation must be accompanied by environmental sustainability. Intensive agriculture can increase pressure on groundwater, soil nutrients and agro-ecosystems if fertilisers, pesticides and water are used inefficiently.

Sustainable farming in Mandya can include:

- integrated nutrient management;
- integrated pest management;
- soil testing;
- organic manure and compost;
- crop rotation;
- water-saving irrigation;
- farm ponds and rainwater harvesting;
- mulching;
- reduced chemical use;
- residue management; and
- integrated crop-livestock systems.

ICAR emphasises resource-use optimisation, sustainable production and appropriate engineering technologies as important components of modern agricultural development.

Digital tools can also support sustainability. For example, digital pest-management systems can help farmers identify crop problems and receive scientific recommendations, potentially reducing unnecessary chemical applications.

The concept of sustainability is particularly important in irrigated districts such as Mandya because higher agricultural intensity can increase pressure on water and soil resources. Technology

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should therefore be evaluated not only in terms of increased output but also in terms of water efficiency, soil health, input efficiency and long-term resilience.

9. Major Challenges

Despite considerable technological progress, Mandya agriculture faces several challenges.

9.1 Water Dependence

A substantial part of agriculture depends on irrigation systems. Variations in rainfall and water availability can therefore affect agricultural planning and production.

9.2 Rising Cost of Cultivation

Costs of labour, fertilisers, pesticides, electricity, machinery and other inputs can reduce farm profitability. Mechanisation can reduce labour requirements but may involve substantial investment.

9.3 Labour Shortage

Migration and changes in rural employment have contributed to greater demand for mechanised agricultural operations. Timely access to machinery is therefore increasingly important.

9.4 Climate Variability

Changing rainfall patterns, heat, drought conditions and pest pressures create uncertainty for agricultural production. Climate-resilient crop choices and water-efficient technologies are increasingly important.

9.5 Digital Divide

Although smartphones and digital agricultural services are expanding, not all farmers have equal access to digital information or the skills required to interpret it.

9.6 Market Uncertainty

Crop diversification requires dependable markets. Without appropriate storage, processing and marketing arrangements, farmers may face difficulties in obtaining remunerative prices for alternative crops.

10. Suggestions

Based on the analysis, the following measures can strengthen technology-driven agriculture in Mandya:

1. **Promote water-efficient agriculture:** Greater emphasis should be placed on micro-irrigation, water harvesting and efficient irrigation scheduling.
2. **Strengthen custom-hiring centres:** Small and marginal farmers should have affordable access to tractors, harvesters, drones and other machinery.
3. **Expand digital agricultural extension:** Mobile-based advisories should be available in simple local-language formats and supported by village-level demonstrations.
4. **Encourage suitable crop diversification:** Farmers should receive technical and market support before shifting from established crops.
5. **Promote sustainable soil management:** Soil testing, balanced fertilisation, organic matter management and integrated pest management should be strengthened.
6. **Develop value chains:** Processing, storage, farmer-producer organisations and direct marketing can improve opportunities for diversified agricultural products.
7. **Strengthen farmer training:** KVKs and agricultural departments can expand demonstrations on precision farming, mechanisation, water management and climate-resilient practices.
8. **Integrate technology with traditional knowledge:** Local farming experience should be combined with scientific research rather than completely replaced by technological solutions.

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11. Conclusion

Mandya's agricultural transformation represents a gradual movement from traditional farming towards an increasingly irrigated, mechanised, information-driven and diversified agricultural system. Irrigation, especially the K.R. Sagar system, historically provided the foundation for agricultural intensification and changed the district's cropping structure.

The current phase of transformation is being shaped by mechanisation, digital advisory services, improved agricultural technologies and growing interest in crop diversification and sustainable resource management. Government programmes, agricultural databases and institutions such as ICAR's KVK network provide important support for this transition.

However, technological adoption alone cannot resolve all agricultural challenges. The future of Mandya agriculture depends on combining technological innovation with efficient water management, sustainable soil practices, affordable machinery, reliable markets, farmer education and effective extension services.

The transformation should therefore be understood not simply as a shift from traditional tools to modern machines, but as a broader change in the way agricultural resources, information, labour, technology and markets are organised. A balanced approach combining productivity with environmental sustainability can help strengthen the resilience of Mandya's agricultural economy.

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Pashu Sakhis: The Women Behind Healthy Livestock and Stronger Rural Livelihoods

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The livestock sector serves as a vital cornerstone of India's rural economy, contributing significantly to agricultural GDP and household financial security. However, smallholder and marginal farmers in remote areas frequently face acute challenges due to inadequate, delayed, or costly veterinary services. To address these service gaps, the "Pashu Sakhi" (Community Animal Health Worker) model was institutionalized under programs like the Deendayal Antyodaya Yojana – National Rural Livelihoods Mission (DAY-NRLM) and Mahila Kisan Sashaktikaran Pariyojana (MKSP). Selected from local Self-Help Groups, Pashu Sakhis are trained rural women who provide doorstep primary animal healthcare, advisory extension, preventive care (such as deworming and vaccination assistance), and disease surveillance for 100–200 rural households. By translating complex scientific husbandry practices into simple local dialects, these community workers act as a crucial last-mile bridge connecting research institutions, veterinary departments, and livestock farmers. Beyond improving livestock health and productivity, the model transforms traditional, invisible female farm labor into recognized community leadership, financial agency, and social empowerment. Despite operational challenges including irregular training, limited equipment, and ambiguous boundaries regarding formal veterinary care, the model offers a highly scalable, gender-sensitive, and demand-driven paradigm. Strengthening Pashu Sakhis through continuous capacity building, digital advisory integration, and formal institutional recognition can significantly enhance rural livelihood resilience and accelerate sustainable livestock-led agricultural growth.

1. Introduction

India's livestock sector stands as a major contributor to the national economy, demonstrating remarkable resilience and global competitiveness. Livestock sector contributes 5.5 per cent to national GDP and 30.8 per cent to agriculture and allied sector GDP in 2022-2023, it has experienced a strong 12.99 per cent Compound Annual Growth Rate (CAGR) since 2014 (PIB, 2024). In order to accelerate the growth rate, building up of effective technology delivery system is a necessity. Livestock rearing is a vital source of livelihood for rural households in India, particularly for small and marginal farmers, yet the access to affordable and timely veterinary services remains limited in remote areas and traditional dependence on government veterinary services often results in delayed treatments and increased livestock mortality. To address such challenges, bridge the existing service gaps and promote women's empowerment through livelihood generation, a community-based livestock extension model was developed known as Pashu Sakhi model. Pashu Sakhis are Community Animal Health Workers (CAHWs), who are local

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rural women trained as community para-extension and animal health workers in rural India. Even rapid mass communication through ICT cannot match personalized, animal-specific service delivery. Their contribution is critical in remote, low-resource areas with minimal access to formal veterinary services (Alders, 2024).

The Pashu Sakhi model was first implemented in 2013 under the Jharkhand Opportunities for Harnessing Rural Growth (JOHAR) Programme, financially supported by the World Bank (Leitch *et al.*, 2020). The Pashu Sakhi model was formally adopted and scaled nationally under Deendayal Antyodaya Yojana – National Rural Livelihoods Mission (DAY-NRLM) in 2015-2016. Building on this success, the model was subsequently scaled up across multiple Indian states, including Bihar, Rajasthan, Maharashtra, Haryana and Uttar Pradesh, with technical and financial supported extended from organizations such as the Bill & Melinda Gates Foundation, the Aga Khan Foundation, Tata Trusts, The Goat Trust and The Nudge Foundation.

Pashu Sakhi is an institutional innovation at grass root level for an extension and input delivery to the livestock communities who are often ignored and poorly recognized in the conventional extension system. The Pashu Sakhi model aimed to train rural women, generally aged 20–45 years with basic literacy of 8th grade, to provide doorstep animal healthcare and advisory services to 100–200 households within their villages. Pashu Sakhis are trained women selected from Self-Help Groups or village organizations who provide primary animal healthcare, preventive veterinary services, livestock management guidance and extension support at the village level. They are not veterinary doctors, but they are trained to perform specific functions under the supervision of qualified veterinarians and the state animal husbandry department. Their role is comparable to the community health worker model in public health, where local women bridge the gap between formal institutions and rural households.

How rural women are becoming the trusted link between livestock farmers, scientific knowledge and veterinary services

In a small village, when a cow stops eating, a goat falls sick or a calf develops diarrhoea, the first person a livestock farmer may think of is not always the veterinary doctor. It may be a woman from the same village who understands the local conditions and is only a phone call away. She is the Pashu Sakhi. The word Sakhi means a friend. In livestock development, the Pashu Sakhi is much more than a friend to farmers. She is a trained community-level livestock resource person who helps farmers access knowledge and basic livestock services. By taking scientific animal husbandry practices closer to households, Pashu Sakhis help bridge an important gap between available knowledge and its actual use at farm level.

Why does the Pashu Sakhi matter?

Livestock is an important component of rural livelihoods. For small and marginal farmers, animals are sources of milk, meat and eggs, but also assets that provide income, nutrition, employment and financial security. Yet farmers in remote villages may face difficulties accessing timely veterinary advice and scientific information because of distance, limited mobility, inadequate awareness and the cost of repeated visits. This is where community-based extension becomes important. The Mahila Kisan Sashaktikaran Pariyojana (MKSP), implemented as a component of the National Rural Livelihoods Mission, promotes women's participation in agriculture and allied activities and supports community resource persons in livelihood sectors including livestock. (mksp.nrlm.gov.in) The Pashu Sakhi model reflects this approach: train a woman from the community, build her knowledge and skills, and enable her to share that knowledge with fellow livestock farmers.

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From livestock keeper to livestock resource person:

Rural women have traditionally been deeply involved in livestock management. They feed animals, clean sheds, collect fodder, milk animals and care for young stock. However, their contribution has often remained invisible in formal extension systems. The Pashu Sakhi model changes this equation. A woman who understands her community can receive training in scientific livestock management and become a local source of information and support. Official Pashu Sakhi training material emphasizes understanding the livestock kept in the community, their uses, health status and management practices. (mksp.nrlm.gov.in) Her strength is also her proximity to farmers. She speaks the local language, understands local practices and knows the households and their animals. This makes her an important last-mile extension worker.

Pashu Sakhis perform three types of complementary functions:

1. Extension and knowledge sharing of improved animal husbandry practices.
2. Assisting in reporting and controlling livestock disease outbreaks at the village level.
3. Facilitating livestock birth/death registration and providing primary veterinary services at the village level.

Roles and Responsibilities of Pashu Sakhi:

- Working complementarily in technology transfer to farmers engaged in livestock/goat rearing.
- Assisting the nearby veterinary institution to update information on dairy farmers /livestock census.
- Providing information regarding improved fodder crops and livestock feeding systems.
- Reporting to the nearby veterinary institution whenever a disease outbreak is detected in livestock.
- Working as a helper in department programs such as deworming distribution, vaccination programs, and other activities.
- Providing complementary services for artificial insemination and breed development of livestock.
- Pashu Sakhis visiting the villages under their jurisdiction from time to time and working as per the directions of veterinarians for the implementation of department programs.
- Recording daily activities in a diary and reporting to the local veterinary institution.

The emphasis is important: prevention is often better and cheaper than treatment. By encouraging farmers to recognize early warning signs and seek professional veterinary assistance when required, Pashu Sakhis can contribute to reducing avoidable livestock losses.(Government of Karnataka, 2023)

More than a livestock worker: an extension bridge

Agricultural extension has traditionally focused heavily on crops, but livestock is an essential component of many rural farming systems. The Pashu Sakhi provides an important example of community-based, gender-sensitive and demand-driven extension.

She connects: Research institutions → Extension agencies → Veterinary services → Pashu Sakhi → Livestock farmer

Scientific information may be generated by universities and research institutions, but its value is realized only when farmers can understand and apply it.

The Pashu Sakhi can translate technical recommendations into simple, locally understandable messages while carrying farmers' problems back to extension personnel and veterinary

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professionals. Thus, communication is not one-way. She is not merely a messenger of technology. She can also become a messenger of farmers' needs.

When women become change agents

One of the most significant dimensions of the Pashu Sakhi initiative is its potential for women's empowerment. Women contribute substantially to livestock activities, but their work does not always translate into decision-making power, recognition or independent income. Becoming a Pashu Sakhi can help women transform existing knowledge into a recognized community role.

An example documented under MKSP describes Meera Devi from Rajasthan, who was selected as a Pashu Sakhi after livestock management training. She subsequently trained residents of her village and nearby villages in improved livestock practices and earned additional income by extending her services. (mksp.nrlm.gov.in) Such stories demonstrate an important possibility: the woman once considered only a livestock caretaker can become a livestock knowledge provider, trainer and community leader. The transformation is therefore not only about livestock. It is also about identity, confidence, recognition and agency.

The economic value of a healthy animal

A healthy animal is a productive asset. When disease is prevented, mortality is reduced and feeding and management improve, farmers have greater potential to obtain milk, meat, eggs, offspring and other livestock products. Better livestock management can therefore contribute to household income and livelihood security. Recent ICAR initiatives have similarly emphasized skill development, scientific animal husbandry and women-led livestock enterprises for strengthening rural livelihoods. (icar.gov.in) The Pashu Sakhi fits naturally into this larger vision of women-led, knowledge-based rural development.

Challenges behind the success story The Pashu Sakhi model has enormous potential, but the role should not be romanticized. Pashu Sakhis may face inadequate or irregular training, limited access to medicines and equipment, insufficient remuneration, lack of mobility, uncertainty about their role and limited institutional recognition. Another important issue is the boundary between basic livestock advisory services and professional veterinary care. A Pashu Sakhi can support farmers through preventive care, awareness, basic services within her training and timely referral. However, serious disease conditions, diagnosis, surgery, prescription of veterinary medicines and other professional procedures require qualified veterinary personnel. Therefore, the Pashu Sakhi should not be seen as a replacement for a veterinarian.

What can make the Pashu Sakhi model stronger?

1. Continuous technical training

Regular refresher training should cover animal nutrition, disease prevention, reproductive management, climate-resilient livestock practices, biosecurity and emerging technologies.

2. Stronger convergence

Pashu Sakhis should be effectively connected with veterinary departments, Krishi Vigyan Kendras, agricultural universities, livestock development agencies, dairy cooperatives and other extension institutions.

3. Digital support

Mobile phones can provide advisory information, disease alerts, training videos, expert consultations and farmer records.

4. Recognition and remuneration

If Pashu Sakhis provide valuable community services, their work needs appropriate recognition and sustainable livelihood opportunities.

5. Building leadership

Training should develop communication, group facilitation, entrepreneurship, record keeping and leadership skills alongside technical knowledge.

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Way Forward

The future of livestock extension cannot depend only on institutions located far from villages. It must increasingly involve local people, local knowledge and locally accessible services. The success of livestock development is ultimately measured by whether scientific knowledge reaches the animal shed, whether farmers adopt better practices, whether livestock remain healthier and whether rural families improve their livelihoods. The Pashu Sakhi stands at precisely this point of connection. She carries knowledge from the training room to the cattle shed. She carries farmers' concerns from the village back to institutions. She connects women with opportunities, encourages preventive care and promotes scientific livestock management. Most importantly, she demonstrates that rural women are not merely beneficiaries of agricultural development. They can be its frontline agents.

A woman, a resource and a catalyst for change

The story of the Pashu Sakhi is ultimately a story about changing the way we think about rural extension. For decades, development programmes have asked how technology can reach farmers.

The Pashu Sakhi model encourages us to ask: What happens when the farmer herself becomes part of the extension system?

A woman trained in scientific livestock management can become a source of knowledge for her neighbours. A livestock keeper can become a community resource person. A village-level worker can become a link between farmers and institutions. With knowledge, institutional support and recognition, she can help create something much larger: healthier livestock, informed farmers, stronger women and more resilient rural livelihoods. The Pashu Sakhi may begin her journey with a few animals and a few households around her.

But with the right support, she can help open the door to a new model of rural development.

Conclusion

The Pashu Sakhi model represents a transformative shift in agricultural extension, moving from traditional top-down information dissemination to a decentralized, gender-sensitive, and community-led paradigm. By capitalizing on the central role that rural women historically play in daily livestock management, this institutional innovation effectively addresses the long-standing last-mile delivery deficit in primary veterinary healthcare and extension services. Pashu Sakhis successfully bridge the critical gap between formal scientific research institutions, state veterinary departments, and resource-poor farming households, ensuring that timely advisory, disease prevention, and management practices reach the cattle shed directly.

Beyond the tangible economic benefits of reduced livestock mortality, enhanced animal productivity, and improved household livelihood stability, the model's most profound impact lies in social transformation. It systematically elevates rural women from silent, unpaid caregivers to recognized community resource persons, trainers, and economic change agents.

However, realizing the full long-term potential of the Pashu Sakhi framework requires addressing structural bottlenecks. Establishing clear boundary definitions between primary health advisory and professional veterinary practice is essential to complement, rather than substitute, formal veterinary networks. Furthermore, sustaining this momentum necessitates continuous multi-disciplinary refresher training, integration with digital extension tools (such as mobile advisory platforms), robust institutional convergence across Krishi Vigyan Kendras (KVKs) and state departments, and fair, sustainable financial remuneration structures. Empowering Pashu Sakhis with technical mastery, institutional support, and formal recognition ensures that rural women remain not merely passive recipients of developmental programs, but active drivers of resilient, sustainable, and inclusive rural economies.

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Weed Management Challenges in Sweet Sorghum Production

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Sweet sorghum [*Sorghum bicolor* (L.) Moench] has emerged as a high-potential multi-purpose bioenergy crop valued for its sugar-rich stalks, grain yield, and high lignocellulosic biomass production. However, weed infestation remains one of the most critical agronomic bottlenecks, causing severe yield losses ranging from **35% to 85%** depending on weed density, species composition, and critical crop-weed competition periods. Sweet sorghum seedlings exhibit slow early growth during the first 3 to 4 weeks after emergence, making them highly vulnerable to aggressive weed competition for light, soil moisture, nutrients, and physical space.

This paper comprehensively examines weed management challenges in sweet sorghum production, analyzing issues specifically through the practical lens of smallholder and commercial farmers. We evaluate the biological and economic trade-offs of existing weed control practices, highlight major advantages and disadvantages of chemical, mechanical, and cultural interventions, and present actionable, low-cost preventive strategies suitable for smallholder adaptation. Integrated Weed Management (IWM) frameworks are proposed to bridge traditional farming wisdom with modern agronomic innovations, ensuring long-term yield optimization, biofuel feedstock viability, and soil health preservation.

2. Introduction

Sweet sorghum [*Sorghum bicolor* (L.) Moench] is a C_4 photosynthetic crop recognized globally for its high biomass production, resource-use efficiency, water-use efficiency, and short growth cycle (90–120 days). Unlike grain sorghum, sweet sorghum accumulates substantial amounts of fermentable sugars (sucrose, glucose, and fructose) in its thick stalks (10–20% brix concentration), making it a premier bioenergy crop for bioethanol production without compromising food security. Furthermore, its grain provides nutritional security for human consumption, while the crushed stalk residue (bagasse) serves as valuable livestock fodder or bio-electricity feedstock.

Key Crop Characteristics & Agro-Ecological Significance

Sweet sorghum thrives in semi-arid and tropical regions with rainfall between 500–700 mm. Its deep root system and high physiological temperature tolerance allow it to yield substantial biomass under marginal soil conditions where sugarcane or corn fail to produce economically viable yields.

Despite its tremendous agricultural potential, sweet sorghum productivity is heavily constrained by biotic stresses, among which weed competition ranks highest in economic severity. The slow initial canopy development of sweet sorghum seedlings creates an ideal ecological niche for rapid weed colonization. Uncontrolled weeds compete aggressively for soil nitrogen, phosphorus, potassium, and soil moisture during early physiological stages.

Critical Period of Crop-Weed Competition (CPCWC)

The Critical Period of Crop-Weed Competition in sweet sorghum typically extends from **15 to 45 days after sowing (DAS)**. Crop yields suffer irreversible losses if fields are not kept weed-free during this

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developmental window. The mathematical relationship governing economic yield loss (Y_{loss}) relative to weed density (W_d) and competition duration (t) highlights the necessity of timely intervention:

Economic Yield Loss Equation:
$$Yloss = Ymax \times [1 - exp(-k \cdot Wd \cdot t)]$$

Where Ymax represents maximum potential stalk yield under weed-free conditions, and k represents the crop-specific weed competition coefficient. High weed populations during the CPCWC severely suppress stem diameter, leaf area index (LAI), stalk juice extraction percentage, and sugar concentration (°Brix).

Predominant Weed Flora in Sweet Sorghum Ecosystems

Weeds infesting sweet sorghum fields are ecologically categorized into three primary functional groups, each presenting distinct physiological competition mechanisms:

Weed Category	Major Species Identified	Growth Habit & Impact Level
Grasses (Monocots)	*Echinochloa colona*, *Dactyloctenium aegyptium*, *Digitaria sanguinalis*, *Setaria verticillata*	Fast early germination, dense shallow roots; competes intensely for early nitrogen and moisture. High risk of crop smothering.
Sedges	*Cyperus rotundus*, *Cyperus esculentus*	Perennial propagation via extensive underground tubers/rhizomes; extremely hard to eradicate; severe early-stage competition.
Broadleaf Weeds (Dicots)	*Trianthema portulacastrum*, *Amaranthus viridis*, *Parthenium hysterophorus*, *Digera arvensis*	Rapid canopy formation, high transpiration rates; shades sorghum seedlings and competes heavily for solar radiation and potash.
Parasitic Weeds	*Striga asiatica*, *Striga hermonthica (Witchweed)*	Root hemiparasite; attaches directly to sorghum roots, siphoning nutrients and water; causes complete crop failure in endemic areas.

3. Weed management challenges in farmers' perspectives

From the operational and socio-economic standpoint of farmers, particularly small and marginal landholders in tropical and semi-arid regions, managing weeds in sweet sorghum involves complex practical hurdles. Field studies and direct extension interactions highlight key constraints:

3.1 Morphological Similarity at Early Growth Stages

One of the most immediate challenges reported by farmers is the visual similarity between sweet sorghum seedlings and wild grassy weeds (e.g., *Echinochloa colona* and *Dactyloctenium aegyptium*) during the 1-to-3 leaf stage (up to 15 DAS). Unskilled agricultural laborers often struggle to

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distinguish crop plants from weeds, leading to accidental uprooting of young crop plants or leaving invasive weeds untouched during initial manual weeding passes.

3.2 Labor Shortages and Rising Wage Rates

Manual weeding remains the primary weed control technique across developing agrarian economies. However, peak weed management directly coincides with the high-demand agricultural season for major staple crops. Farmers face acute shortages of skilled farm labor, causing delays in weeding beyond the critical competition period (past 30 DAS). Furthermore, escalating daily wage rates significantly increase the cost of cultivation, eating into farming profit margins.

3.3 Weather Constraints and Field Accessibility

Sweet sorghum is primarily grown during the rainy (Kharif) season. Continuous monsoonal rainfall leads to prolonged soil saturation, rendering fields physically impassable for manual labor, bullock-drawn weeders, or tractor-mounted cultivators. Rain events immediately following herbicide application often wash away pre-emergence chemicals, resulting in control failure and requiring costly secondary treatments.

3.4 Herbicide Selectivity and Crop Phytotoxicity

Sweet sorghum exhibits heightened physiological sensitivity to many common post-emergence herbicides compared to grain sorghum or corn. Farmers frequently report crop injury, leaf chlorosis, growth retardation, and reduced stalk diameter when applying systemic broadleaf herbicides (such as 2,4-D formulations) if applied late or at incorrect dosages. Furthermore, limited availability of selective post-emergence herbicides specifically labeled for sweet sorghum leaves farmers with very restricted chemical choices.

3.5 Parasitic Weed Infestation (Striga spp.)

In parasitic weed endemic zones, farmers face severe yield destruction from *Striga asiatica*. Because *Striga* inflicts significant physiological damage underground before emerging above the soil surface, traditional surface weeding practices prove ineffective. Farmers lack access to resistant cultivars or cost-effective suicidal germination stimulants, causing long-term land abandonment in extreme cases.

3.6 Economic Constraints and Resource Scarcity

Smallholder farmers operating on thin financial margins often defer weed management due to upfront liquidity constraints for purchasing pre-emergence herbicides or hiring weeding labor. Delayed weeding allows weeds to set seeds, replenishing the soil weed seed bank and compounding infestation intensity for subsequent cropping cycles.

4. DISADVANTAGES AND ADVANTAGES OF WEED MANAGEMENT APPROACHES

Effective weed management relies on understanding the strategic advantages and inherent limitations of various control paradigms. Below is a comparative assessment of chemical, mechanical, manual, and cultural weed management methods in sweet sorghum production.

Advantages

Chemical Control (Pre-emergence): Rapid application, protects crop during early critical period (0–25 DAS), highly cost-effective per hectare compared to manual labor.

Mechanical Inter-cultivation: Aerates topsoil, improves rainwater infiltration, destroys inter-row weeds efficiently without chemical residues.

Manual Weeding / Hand Hoeing: Achieves complete intra-row weed removal, eliminates morphologically similar grassy weeds, highly adaptable to irregular field topographies.

Cultural & Cover Crop Strategies: Enhances soil organic matter, suppresses weed seed germination naturally through shading, improves overall soil health.

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Integrated Approach (IWM): Minimizes herbicide resistance risk, lowers long-term weed seed bank density, balances economic returns with ecological sustainability.

Disadvantages

Chemical Risks: High risk of crop phytotoxicity if misapplied; soil residual carryover may harm succeeding pulse crops; accelerates herbicide-resistant weed biotypes.

Mechanical Limitations: Cannot control weeds within the crop row (intra-row space); requires precise row spacing at planting; unusable in wet soils.

Manual Control Constraints: Extremely labor-intensive (requires 25–30 worker-days/ha), slow operational speed, highly expensive during peak season labor shortages.

Environmental Concerns: Excessive tillage promotes soil erosion, destroys soil structure, and accelerates soil moisture evaporation in dryland regions.

Parasitic Weed Ineffectiveness: Surface removal fails to prevent underground root damage caused by parasitic species like Striga.

Detailed Comparative Assessment Matrix

Management Method	Target Weed Spectrum	Labor Requirement	Efficacy Window & Environmental Impact
Pre-Emergence Herbicides (Atrazine / Pendimethalin)	Broadleaf weeds & annual grasses	Very Low (1–2 days/ha)	0–30 DAS Potential chemical runoff; minor soil microbial disruption if overused.
Mechanical Inter-cultivation (Blade hoe / Cultivator)	Inter-row annual weeds	Low–Medium (Tractor / Bullock)	15–35 DAS Improves soil aeration; potential root pruning of crop if executed too close.
Manual Hand Hoeing	All species (including intra-row)	High (25–30 days/ha)	15–45 DAS Zero chemical impact; physical disturbance of surface mulch.
Integrated Weed Control (Pre-em + 1 Hand Hoeing)	Comprehensive (Grasses, Broadleaf, Sedges)	Moderate (8–10 days/ha)	Full Season (0–60 DAS) Optimal balance: reduces chemical load while preserving soil health and yield.

5. preventive measures in farmers' perspective

Preventive weed management forms the first line of defense in sustainable sweet sorghum farming. By preventing weed introduction, seed production, and establishment, farmers can drastically reduce control costs during the cropping season. Practical, low-cost preventive measures tailored for farming communities include:

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5.1 Use of Certified Clean Crop Seeds

Farmers must utilize certified, weed-seed-free sorghum seed stocks. Farm-saved seeds should be thoroughly cleaned using sieves, winnowing, or brine solution flotation to eliminate weed seed contaminants (especially parasitic *Striga* seeds and wild sorghum species) prior to sowing.

5.2 Stale Seedbed Technique

The stale seedbed technique is a highly practical, low-cost preventive strategy for smallholder farmers:

Step 1: Prepare the seedbed 2–3 weeks before planned crop sowing following early pre-monsoon rains or a light irrigation.

Step 2: Allow flush weed seeds residing in the topsoil layer to germinate naturally.

Step 3: Destroy the emerged weed flush using light shallow tillage, a hoe, or a non-selective contact herbicide (e.g., Glyphosate or Paraquat) without disturbing deeper soil layers.

Step 4: Sow sweet sorghum seeds directly with minimal soil disturbance. This reduces initial weed pressure during the critical early crop growth period by up to 60%.

5.3 Well-Composted Farmyard Manure (FYM) Usage

Uncomposted or partially decomposed cattle manure is a major primary vector for introducing viable weed seeds (such as *Cyperus rotundus* and *Amaranthus* spp.) into arable fields. Farmers should adopt proper aerobic composting or pit thermophilic composting techniques, ensuring internal compost pile temperatures reach **55–60°C** to destroy weed seed viability before land application.

5.4 Clean Equipment and Irrigation Management

Machinery, tractors, blades, and seed drills shared among community farms often transport weed seeds and underground rhizomes between fields. Thoroughly washing tillage implements before entering clean fields prevents cross-contamination. Additionally, irrigation canals should be fitted with simple mesh filters to intercept floating weed seeds.

5.5 Strategic Crop Rotation and Intercropping

Continuous sorghum monoculture encourages dominant weed species and parasitic *Striga* buildup. Rotating sweet sorghum with broadleaf legumes (e.g., cowpea, groundnut, soybean, or pigeonpea) breaks weed life cycles. Legume intercropping (e.g., Sorghum + Cowpea in 2:1 paired row system) provides quick ground cover, smothering intra-row weeds and fixing atmospheric nitrogen.

> **Farmer-Centric Preventive Checklist for Sweet Sorghum:**
> ✓*Adopt narrow row spacing (45 cm vs standard 60 cm) where soil moisture permits to accelerate canopy cover.*
> ✓*Practice deep summer plowing to expose weed tubers and perennial rhizomes to extreme solar heat (solarization).*
> ✓*Field sanitation: Keep field bunds, irrigation channels, and fence lines clean to prevent weed seed dispersal into crop areas.*

6. Conclusion

Sweet sorghum holds immense promise as a multi-purpose biofuel, food, and fodder crop capable of driving sustainable bio-economies in semi-arid environments. However, realizing its maximum stalk yield, sugar concentration (°Brix), and grain output requires overcoming severe early-season weed management challenges. Slow initial seedling growth during the first 30 days leaves the crop exceptionally vulnerable to weed competition, resulting in substantial economic losses if unmanaged.

Addressing weed management from the farmer's perspective reveals clear operational constraints: acute labor shortages, high wage costs, adverse weather preventing field entry, and risks of herbicide toxicity. Solitary weed control methods—whether

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purely chemical, mechanical, or manual—fail to offer a complete, sustainable solution. Sole reliance on chemicals risks herbicide resistance and environmental degradation, while exclusive manual labor is economically unsustainable for medium-to-large farming operations.

The path forward lies in the widespread adoption of **Integrated Weed Management (IWM)** tailored to smallholder farm contexts. Combining preventive strategies (stale seedbed preparation, certified seed selection, clean composting) with judicious pre-emergence herbicide applications (Atrazine @ 0.5–1.0 kg a.i./ha), timely mechanical inter-cultivation at 25–30 DAS, and smother-crop intercropping provides a robust, cost-effective, and ecologically sound framework. Educating farmers through participatory field extension on early weed identification and critical competition windows will safeguard sweet sorghum yields, protect farming profitability, and support sustainable agricultural growth.

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From Collective Action to Economic Empowerment: Performance Analysis of FPOs in strengthening farmers

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Farmer Producer Organizations (FPOs) have emerged in India as a major institutional innovation to strengthen the economic conditions of small and marginal farmers by enabling collective action. Collective action refers to farmers organizing themselves to pool resources, access markets, inputs, services, and negotiate prices collectively, which individually they cannot achieve due to constraints of scale, finance, or market power. Through collective action, FPOs aim to enhance farmers' economic empowerment—improved income, better market access, financial inclusion, technical knowledge, and stronger bargaining power.

The rapid expansion of FPOs across various Indian states signifies the transition from individual farming to collective enterprise that can foster rural economic transformation.

It serves as the backbone of rural livelihoods and contributing significantly to food security, employment and economic development. Agricultural risk is high for small and marginal farmers due to climate vagaries, uncertain production conditions, lack of support services, alternate markets and poor infrastructure. There has been a significant gap in agricultural insurance coverage among farmers and thereby, farmers are vulnerable to monsoon and market risks. (Greatrex *et al.*2015).

Farmer Producer Organization (FPO) is a registered group of farmers who come together to collectively perform various agricultural and business activities, including input purchase, crop planning, marketing, processing and export. FPO is typically a society or company consisting of farmers who are actual producers of specified commodities. These organizations are registered under the Mutually Aided Cooperative Societies (MACS) Act 1995 or as a Farmers Producer Company (FPC) under the Companies Act 2013. FPOs are formed at cluster, block, district or state levels depending on the needs of producers and the demand potential, with a value chain approach to enhance economic and social benefits for farmers (Sangappa and Rafi, 2023).

Government agencies like SFAC (Small Farmers' Agribusiness Consortium) and NABARD (National Bank for Agriculture and Rural Development) have been instrumental in supporting FPOs through funding, training and policy support, particularly targeting marginalized communities. As of 2023, over 10,000 FPOs were operational in India, with at least 3,000+ focusing on tribal or backward areas (SFAC, 2023).

The Government of India has launched a Central Sector Scheme for Formation and Promotion of 10,000 FPOs (2020–2025) with a budget of ₹6,865 crores to support these efforts. (MoA&FW, 2021).

Concept and Evolution of FPOs

Definition: An FPO is a registered collective of farmers, typically under the Companies Act, that works to improve members' incomes through collective production, procurement, and marketing.

Evolution: The Small Farmers' Agribusiness Consortium (SFAC) and NABARD have been instrumental in promoting FPOs since the early 2000s.

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FPOs as interventions:

Farmer Producer Organizations (FPOs) have emerged as significant interventions to address these systemic challenges. FPOs enable farmers to pool resources, access markets collectively, and negotiate better terms with buyers. Studies show that FPOs enhance price realization, reduce transaction costs, and promote sustainable farming practices (Singh, 2016). In India, successful FPO models like AMUL and eNAM have demonstrated how collective action can transform the agricultural sector. Globally, organizations such as farmer cooperatives in Kenya and producer groups in the European Union have shown similar success in empowering smallholder farmers. These interventions not only provide economic benefits but also foster social cohesion, enabling farmers to become active participants in decision-making processes (World Bank, 2020).

Action to Empowerment:

Collective action leads to:

- Aggregation of produce: allowing bulk marketing and access to larger buyers
- Shared resources and inputs: cheaper seeds, fertilizers, equipment
- Knowledge pooling: better farming techniques, extension services
- Increased bargaining power: against traders and intermediaries

These dimensions together contribute to economic empowerment, defined as increased income, financial autonomy, and improved decision-making capacity in economic activities.

A conceptual analysis of the role of FPOs in economic independence and upliftment is captured in research showing how collective structures enhance access to credit, markets, and bargaining positions, contributing to rural prosperity and empowerment outcomes. (Sarkar et al., 2022).

How FPOs are strengthening farmers

1.Collective input procurement

2.Better access to market

3.Access to credit and financial services

4.Improved bargaining power

5.Reduction in production and marketing costs6.Improved access to government schemes and services

Factors influencing the Performance of FPOs

Education, annual income, leadership ability, economic motivation, achievement motivation, risk orientation, extension contact, social participation and mass media exposure had positive and significant effects on overall FPO performance.

Measuring Performance of FPOs:

Performance analysis of FPOs is crucial to evaluate their effectiveness in achieving economic empowerment. Performance can be assessed on multiple dimensions:

Economic & Financial Performance

- Turnover and profitability
- Paid-up capital and working capital
- Income growth of members

A study surveying 125 FPOs across Andhra Pradesh, Madhya Pradesh, Telangana, Maharashtra, and Uttar Pradesh used regression analysis to identify key determinants of performance, finding that paid-up capital, member size, and years of existence significantly influence the financial performance of FPOs. It also identified capital requirements as a major constraint to performance growth.(Kumar et.al,2023).

Marketing and operational Performance

Performance is also measured by services provided:

- Access to quality inputs
- Market information and fair price realization

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- Linkages with extension services
- Trust and group cohesion among members

Link to Economic Empowerment

The performance of FPOs is strongly linked to economic empowerment outcomes:

- Increased income and price realization
- Financial inclusion through credit access
- Enhanced capacity for entrepreneurial activities
- Greater resilience against market risks

Challenges Limiting Performance

Despite the strengths, FPO performance is constrained by:

- Insufficient capital and financing mechanisms
- Weak managerial capacity
- Limited market infrastructure
- Policy and regulatory hurdles

These challenges can restrict the trajectory from collective action to meaningful economic empowerment unless addressed through supportive policies and capacity building.

Case study on FPOs of Rewa district:

Vindhyanchal Crop Producer Company and Gangev Agro Farmer Producer Company (FPOs were registered under company's act). Vindhyanchal Crop Producer Company was founded on 2017, it has 1050 members and Gangev Agro Farmer Producer Company was founded on 2021, has 750 members. Activities involved in Vindhyanchal FPO are seed and millet processing and Gangev FPO are involved in value chain, wheat and paddy processing. (Source: Nabard office, Rewa)

Fig: Vindhyanchal and Gangev Agro Farmer Producer Company

What does the study reveal about the performance of FPOs

Overall, the findings indicate that FPOs have considerable potential to strengthen farmers economically and institutionally. However, sustained improvement requires greater access to finance, extension services, technical guidance, market linkages, storage facilities, digital knowledge and capacity-building programmes.

Several implications for FPO managers, extension agencies and policymakers:

1.Strengthening financial access: FPO members should be facilitated in obtaining timely and affordable credit through appropriate financial linkages.

2.Improving extension services: Regular field visits, farmer advisory services and technical guidance should be strengthened.

3.Capacity building: Regular training programmes should be organised on production technologies, post-harvest management, quality standards, marketing and organisational management.

4.Market development: FPOs should strengthen direct market linkages and collective marketing arrangements to improve farmers' price realization and reduce dependence on intermediaries.

5.Storage and infrastructure: Adequate storage, transportation and processing facilities should be

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developed to support bulk procurement and marketing.

6.Digital capacity: Farmers should be trained in the use of ICT tools and digital platforms relevant to agriculture and marketing.

7.Member participation: Greater opportunities should be created for members to participate in organisational decision-making and governance.

8.Institutional strengthening: FPOs should focus on improving governance, managerial efficiency and organisational capacity for long-term sustainability.

Conclusion

From individual farmers acting alone to collective entities driving economic change, FPOs represent a critical institutional framework for improving farmers' economic conditions. The performance analysis from various research contexts highlights that:

- Financial infrastructure, institutional mechanisms, and service delivery are core drivers of FPO success.
- Effective FPOs show measurable gains in income and widening access to markets.
- Continued research and targeted support are essential to sustain and scale FPO performance.

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Climate-Resilient Agronomy Practices for Jute Production

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Jute (Corchorus olitorius and Corchorus capsularis) is a critical natural fiber crop facing significant yield and quality risks due to climate change dynamics, including erratic rainfall, early-season droughts, waterlogging, and escalating pest pressures. This document outlines climate-resilient agronomy strategies designed to sustain jute production while optimizing resource efficiency. Key interventions include adopting stress-tolerant cultivars (such as JRO-204 and JBC-5), implementing conservation tillage and raised-bed planting, precision line sowing to reduce seed rates, and applying integrated nutrient management (STCR and biofertilizers). Furthermore, modern post-harvest technologies, including ribbon retting and microbial consortium formulations (e.g., CRIJAF Sona), address severe water scarcity during processing by cutting water usage by up to 60% and shortening retting cycles. Adopting these integrated practices enhances smallholder adaptive capacity, protects fiber quality, and ensures sustainable, low-carbon jute production.

1. Introduction & Climate Vulnerabilities in Jute Cultivation

Jute (Corchorus olitorius and Corchorus capsularis), known as the 'Golden Fibre', is one of the most essential natural bast fiber crops globally. It plays a vital socio-economic role in tropical agricultural economies. However, climate change poses severe risks to traditional jute farming systems due to erratic precipitation patterns, prolonged dry spells during early vegetative growth, severe waterlogging during late vegetative stages, rising temperatures, and heightened pest/disease outbreaks.

Adopting climate-resilient agronomic practices is essential to maintain fiber yield and quality, protect farmer livelihoods, and enhance resource-use efficiency under changing climatic conditions.

2. Climate-Resilient Cultivars & Stress-Tolerant Varieties

Selecting stress-adapted varieties is the first line of defense against abiotic and biotic climate stresses:

- **Drought and High Temperature Tolerant Varieties:** Improved cultivars such as JRO-204 (Suren), JRO-5408, and JRCM-2 exhibit better deep-rooting architecture and stomatal regulation, enabling survival during early-season dry spells.
- **Waterlogging & Premature Flowering Tolerant Varieties:** Varieties like JBC-5 (Robi Jute) and JBO-1 demonstrate resilience against pre-monsoon excessive rainfall and water stagnation without undergoing premature flowering.
- **Disease-Resistant Lines:** Use of stem-rot and root-rot resistant selections minimizes crop loss during high-humidity flood events.

3. Precision Land Preparation & Resource-Conserving Tillage

Conventional intensive tillage causes soil carbon loss and moisture depletion. Climate-resilient soil management emphasizes conservation practices:

- **Minimum/Reduced Tillage & Bed Planting:** Sowing on raised beds or practice reduced tillage preserves soil structure, reduces fuel costs, improves infiltration, and prevents waterlogging around root zones during high-intensity rainfall.

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- **Laser Land Leveling:** Ensures uniform distribution of irrigation water, improves drainage efficiency, reduces seed loss during heavy rain, and optimizes nutrient uptake.

4. Sowing Management & Crop Geometry Optimization

Adjusting crop geometry and sowing schedules mitigates risks from shifting seasonal schedules:

- **Line Sowing with Seed Drills:** Replacing traditional broadcasting with line sowing (spacing 20 cm × 5-7 cm) reduces seed rate by 40-50% (from 7-8 kg/ha to 4-5 kg/ha), facilitates mechanical weeding, and improves microclimate aeration.
- **Adjusted Sowing Windows:** Utilizing weather-forecast-based sowing dates avoids early moisture stress or unexpected deluge during germination.

Table 1: Climate-Resilient Agronomy Matrix for Jute Production

Climate Stress	Agronomic Strategy / Intervention	Expected Climate Resilience Benefit
Early-Season Drought	Seed priming with 1% KNO3/water; Line sowing; Organic mulching	Enhances germination speed, root vigor, and soil moisture retention.
Waterlogging / Heavy Rain	Raised bed planting; Field border drainage channels; JBC-5 selection	Prevents root hypoxia, seedling mortality, and premature flowering.
Soil Carbon Depletion	Incorporation of crop residue; Green manuring (Crotalaria juncea)	Improves organic carbon, moisture holding capacity, and microbial life.
Pest/Disease Outbreaks	IPM with bio-agents (Trichoderma viride); Neem oil sprays	Reduces synthetic chemical reliance and crop damage under warm humid conditions.

5. Integrated Nutrient & Water Management

- **Soil Test Crop Response (STCR) Fertilization:** Balanced application of NPK along with micronutrients like Zinc and Boron builds crop resistance against thermal and drought stress.
- **Biofertilizers & Organic Amendments:** Inoculation with Azotobacter, PSBs, and Arbuscular Mycorrhizal Fungi (AMF) enhances nutrient bio-availability and root adaptation under extreme moisture regimes.
- **Alternate Wetting and Drying (AWD) & Micro-Irrigation:** In dry conditions, controlled irrigation saves up to 30% water while maintaining optimal stalk development.

6. Eco-Friendly & Eco-Efficient Retting Technologies

Traditional retting requires huge water bodies, which are becoming scarce due to climate-driven droughts. Resilient alternatives include:

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- **Microbial Microbial Consortium Retting (e.g., NISO/CRIJAF Sona):** Reduces retting duration from 21 days to 12-15 days, improves fiber grade by 1-2 ranks, and consumes significantly less water.
- **Ribbon Retting & Tank Retting with Water Recirculation:** Ribboning reduces required water volume by up to 60%, overcoming severe water scarcity challenges during post-harvest months.

7. Conclusion & Recommendations

Transitioning to climate-resilient agronomy in jute production is imperative for sustainable agriculture. Implementing integrated strategies—including stress-tolerant varieties, line sowing, precision nutrient delivery, and eco-friendly ribbon/microbial retting—secures crop yields, preserves natural resources, and improves smallholder farmers' climate adaptive capacity.

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Natural Farming: A Path towards Sustainable, Chemical-free and Climate-resilient Agriculture

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Natural farming has emerged as one of the most widely discussed alternatives to input-intensive, chemical-based agriculture in India. Rooted in the idea of working with nature rather than against it, natural farming relies on on-farm biomass recycling, cow-dung-and-urine-based formulations, live mulching, multi-cropping and the near-total exclusion of synthetic fertilisers and pesticides. Over the past decade, natural farming has moved from being a fringe practice promoted by a few innovative farmers to a mainstream policy priority, backed by dedicated central and state schemes such as the Bhartiya Prakritik Krishi Paddhati (BPKP), the National Mission on Natural Farming (NMNF) and, in Andhra Pradesh, the globally recognised Andhra Pradesh Community Managed Natural Farming (APCNF) programme. This article presents a popular overview of the concept, current status, major promotional schemes, benefits, limitations and future outlook of natural farming, with the objective of creating awareness among farmers, students and extension functionaries.

1. Introduction

Indian agriculture, since the Green Revolution, has depended heavily on chemical fertilisers, synthetic pesticides and high-yielding varieties to feed a growing population. While this strategy achieved food security, it also brought soil degradation, declining water tables, rising input costs, pest resurgence and residues in food and water. Natural farming, sometimes traced back to the philosophy of "Zero Budget Natural Farming" (ZBNF) popularised by Padma Shri Subhash Palekar, offers a low-external-input alternative built around four pillars: Beejamrutham (seed treatment), Jeevamrutham (a fermented microbial culture applied to soil), Acchadana (mulching) and Whapasa (soil moisture and aeration management). Unlike conventional organic farming, which may still rely on purchased bio-inputs, natural farming emphasises inputs produced on the farm itself using local cattle, crop residue and biodiversity, thereby reducing the cost of cultivation for small and marginal farmers.

2. Status of Natural Farming

Natural farming today occupies an important place in India's agricultural policy landscape. India is recognised as having the largest number of organic and natural farming practitioners in the world, though the area under such practices is still a modest share of the country's total cultivated area. Natural farming was first supported nationally through the Bhartiya Prakritik Krishi Paddhati Programme (BPKP), a sub-scheme launched under the Paramparagat Krishi Vikas Yojana (PKVY) during 2020-21, and was also promoted along the banks of the Ganga under the Namami Gange programme to reduce chemical run-off into the river. Recognising the growing momentum, the Union Cabinet in November 2024 approved the National Mission on Natural Farming (NMNF) as a standalone Centrally Sponsored Scheme, with a total outlay of over Rs. 2,481 crore, targeting about 7.5 lakh hectares through 15,000 farmer clusters across the country.

Andhra Pradesh has been at the forefront of this movement through the Andhra Pradesh Community

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Managed Natural Farming (APCNF) programme, implemented since 2016 by the Rythu Sadhikara Samstha (RySS), a not-for-profit society of the state government. APCNF has grown into one of the largest agro-ecology programmes in the world, currently reaching around 1.8 million farmers across roughly 0.9 million hectares and more than 8,000 gram panchayats, with a long-term vision of making Andhra Pradesh a fully natural-farming state. Reported outcomes include an increase in farmer net incomes in the range of 38 to 66 per cent, savings in irrigation water of up to 50 per cent, and reductions in greenhouse-gas emissions of up to 46 per cent per acre in natural-farming plots compared with conventional plots.

3. Government Schemes Promoting Natural Farming

A number of central and state schemes have been designed specifically to promote natural and chemical-free farming across the country:

1. **Paramparagat Krishi Vikas Yojana (PKVY) and Bhartiya Prakritik Krishi Paddhati (BPKP):** A cluster-based scheme providing financial assistance of about Rs. 12,200 per hectare over three years for training, cluster formation, certification and input support; adopted in states such as Andhra Pradesh, Chhattisgarh, Kerala, Himachal Pradesh, Madhya Pradesh, Odisha, Tamil Nadu and Jharkhand.
2. **National Mission on Natural Farming (NMNF):** A standalone Centrally Sponsored Scheme (approved November 2024) under the Ministry of Agriculture and Farmers' Welfare, providing an output-linked incentive of about Rs. 4,000 per acre for two years, along with training, certification support and creation of natural-input resource centres (Bio-input Resource Centres).
3. **PM Programme for Restoration, Awareness, Nourishment and Amelioration of Mother Earth (PM-PRANAM):** Encourages states to reduce chemical fertiliser consumption and promote balanced and alternative nutrient management, including natural and organic farming.
4. **PM Rashtriya Krishi Vikas Yojana (PM-RKVY):** A flexible "cafeteria" scheme under which states can select components such as organic farming, soil health management and agroforestry to suit local priorities, with natural farming as one of the sustainability options.
5. **Andhra Pradesh Community Managed Natural Farming (APCNF):** A state-driven programme implemented by RySS, working through women self-help groups and trained Community Resource Persons (CRPs) to build farmer-to-farmer extension networks for natural farming.
6. **Mission Organic Value Chain Development for North Eastern Region (MOVCDNER) and Participatory Guarantee System (PGS-India):** Support organic and chemical-free value chains and certification, complementing natural-farming promotion.

Krishi Vigyan Kendras (KVKs), as the district-level knowledge and technology hubs of the Indian Council of Agricultural Research (ICAR), play a critical role in demonstrating natural-farming practices on farmers' fields, conducting front-line demonstrations, training farmers and rural youth, and linking them to these schemes for financial and technical support.

4. Uses and Advantages of Natural Farming

- Lower cost of cultivation, since farm-produced inputs like Jeevamrutham and Beejamrutham replace costly purchased fertilisers and pesticides, reducing farmer indebtedness.
- Improved soil health through enhanced microbial activity, better soil structure, higher

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organic carbon and improved water-holding capacity.

- Water savings, as mulching and improved soil structure reduce irrigation requirements, which is especially valuable in rain-fed and drought-prone areas.
- Climate resilience, with natural-farming plots showing greater tolerance to dry spells, floods and erratic rainfall compared with conventional monocultures.
- Better food and nutritional quality, as produce is free from synthetic chemical residues, benefitting consumer health.
- Conservation of local livestock breeds and biodiversity, since cattle are integral to preparing natural inputs and multiple crops are grown together.
- Reduced environmental pollution, including lower greenhouse-gas emissions and reduced contamination of soil, ground water and rivers.
- Additional income opportunities through premium markets, direct farmer-to-consumer sales and institutional procurement, such as temple boards sourcing natural-farming produce.

5. Disadvantages and Limitations of Natural Farming

- Yield uncertainty in the initial transition years, as soils accustomed to chemical inputs take time to rebuild biological fertility, sometimes causing temporary yield dips.
- High labour and knowledge intensity, since preparing and applying farm-based inputs regularly demands more labour, skill and monitoring than simply purchasing fertilisers.
- Dependence on livestock, as most natural-farming formulations require access to local desi cattle, which is a constraint for farmers without animals.
- Limited scientific consensus and long-term data on yield stability, nutrient balance and pest and disease management under natural farming across different agro-climatic zones.
- Weak market infrastructure, with inadequate certification systems, branding and premium markets in many regions, limiting the price advantage farmers can realise.
- Scale-up challenges, since replicating community-driven models built on strong social mobilisation, such as APCNF's self-help-group network, is difficult in areas lacking similar institutional capacity.
- Risk of input adulteration and quality variation in farm-prepared formulations, as there are no uniform standards for their composition and efficacy.

6. Awards and Global Recognition

Natural farming in India has received significant international recognition in recent years. The Andhra Pradesh Community Managed Natural Farming (APCNF) programme won the Gulbenkian Prize for Humanity in 2024, described as the world's largest agro-ecology programme, and went on to win the 2026 Food Planet Prize from the Curt Bergfors Foundation, regarded as the world's largest environmental award for food systems, carrying a purse of USD 1.5 million. The award recognised APCNF's success in scaling agro-ecological transition across nearly two million farmers while improving incomes, climate resilience and environmental sustainability. Such recognition has strengthened the case for wider adoption of natural farming as a credible, scalable model for sustainable agricultural development, not only within India but as a reference point for other developing countries.

7. Conclusion

Natural farming represents a promising pathway towards low-cost, ecologically sound and climate-resilient agriculture, particularly suited to the needs

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of small and marginal farmers who form the majority of India's farming community. The growing policy support through schemes such as BPKP, NMNF and state-level initiatives like APCNF reflects a genuine shift in agricultural priorities from mere productivity to sustainability, soil health and farmer welfare. At the same time, natural farming is not a ready-made solution for every situation; the transition period, labour demands, livestock dependence and the need for stronger scientific validation and market linkages must be addressed through sustained research, extension support and farmer capacity-building. Krishi Vigyan Kendras and other extension agencies have a vital role in generating location-specific evidence, conducting demonstrations and handholding farmers through this transition, so that natural farming can move from being a promising alternative to a dependable mainstream practice.

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Impact of Erratic Rainfall on Crop Establishment

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Rainfall is one of the most important climatic factors influencing agricultural production. Crop establishment refers to the successful germination, emergence and early growth of a crop after sowing or planting. Adequate and well-distributed rainfall during this stage is essential for obtaining a uniform plant population. Erratic rainfall means rainfall that is irregular in amount, timing, intensity or distribution. It may occur as delayed rainfall, sudden heavy rainfall, long dry spells or rainfall at an unsuitable time.

Erratic rainfall has become an important challenge for rainfed agriculture. When rainfall does not match the water requirement of the crop, seeds may fail to germinate, seedlings may die and plant stands may become uneven. This ultimately affects crop growth, yield and farm income.

Meaning of Crop Establishment

Crop establishment is the process by which a crop develops a healthy and uniform plant stand after sowing or planting. It includes seed germination, seedling emergence, root development and establishment of sufficient plants per unit area. Good crop establishment provides a strong foundation for later vegetative growth and yield formation.

Meaning of Erratic Rainfall

Erratic rainfall is the occurrence of rainfall with unpredictable timing, amount, intensity or distribution. In agriculture, it may be expressed as late onset of monsoon, early withdrawal of rainfall, prolonged dry periods, intense short-duration rainfall and uneven distribution of rain during the crop season.

Major Effects on Crop Establishment

1. Delayed Germination: When rainfall is delayed after sowing, the soil may not contain enough moisture for seeds to absorb water and begin germination. This delays crop emergence and can reduce the final plant population.

2. Poor and Uneven Emergence: Uneven rainfall creates differences in soil moisture within a field. Some seeds may germinate while others remain dormant, resulting in an uneven crop stand.

3. Seedling Mortality: Heavy rainfall immediately after emergence can cause waterlogging, soil crusting and physical damage to young seedlings. Excess water can also reduce oxygen availability around roots.

4. Soil Erosion and Seed Displacement: High-intensity rainfall may wash away topsoil and expose or bury seeds. It can also create runoff that carries seeds from their original positions.

Impact of Erratic Rainfall on Soil and Seedlings

Erratic rainfall affects the soil moisture balance required for early crop growth. A short period of heavy rain may saturate the soil, followed by rapid drying. Such fluctuations can create stress for germinating seeds and young seedlings.

Soil crust formation is another problem caused by intense rainfall. When soil particles disperse and settle on the surface, a hard layer may form after drying. This layer can restrict seedling emergence and reduce the number of healthy plants.

Heavy rainfall may also cause soil erosion, particularly in sloping or poorly protected fields.

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Loss of fertile topsoil reduces the soil's ability to retain moisture and nutrients. In addition, nutrients may be lost through runoff or leaching.

Waterlogging caused by excessive rainfall reduces the air-filled pore space in soil. Roots require oxygen for respiration, so prolonged waterlogging can restrict root development and weaken young plants.

Effects of Dry Spells

A dry spell immediately after sowing can be highly damaging because seeds require adequate moisture for germination. If the soil dries before germination is completed, seeds may lose viability or seedlings may fail to emerge.

Dry conditions after emergence can cause wilting, poor root development and slow growth. Young plants have a limited root system and are therefore particularly sensitive to moisture stress. In severe cases, re-sowing may be necessary, increasing the cost of cultivation.

Effects on Different Stages of Establishment

During sowing, rainfall determines whether the soil has suitable moisture for seed placement and germination. During germination, sufficient moisture is needed for seed imbibition and metabolic activity. During emergence, excessive rainfall may cause crusting and soil compaction. During early seedling growth, repeated dry and wet conditions can reduce root growth and plant vigour.

Effects on Important Crops

Rice requires adequate water during establishment, but excessive rainfall and prolonged waterlogging can damage young seedlings in unsuitable conditions. In rainfed millets, pulses and oilseeds, delayed rainfall can lead to poor germination and gaps in plant population. Groundnut is especially sensitive to poor soil aeration and excessive moisture during early growth. Maize requires adequate soil moisture for uniform germination and early root development.

Factors That Increase the Impact

The impact of erratic rainfall depends on soil type, crop variety, sowing time, land slope, drainage, seed quality and farm management. Light soils may lose water quickly during dry periods, while heavy soils may remain waterlogged after heavy rain. Fields with poor drainage are more vulnerable to excess rainfall.

Poor-quality seed, improper sowing depth and inadequate land preparation can further reduce crop establishment when rainfall is irregular. Timely sowing and selection of suitable varieties can reduce some of these risks.

Management Practices to Improve Crop Establishment

1. Timely Sowing: Farmers should sow when adequate soil moisture is available and when weather conditions are favourable. Timely sowing helps the crop make better use of available rainfall.

2. Selection of Suitable Varieties: Short-duration, drought-tolerant or locally adapted varieties can help reduce risk under uncertain rainfall conditions.

3. Seed Treatment: Treating seed with recommended biological or chemical seed treatments can protect seeds and young seedlings from certain seed-borne and soil-borne problems.

4. Proper Land Preparation: Good land preparation improves seed-soil contact and helps maintain suitable soil moisture. Conservation practices can also reduce runoff and erosion.

5. Mulching: Crop residues or other suitable mulch materials reduce evaporation, moderate soil temperature and conserve soil moisture during dry spells.

6. Rainwater Harvesting: Farm ponds, contour bunds, check dams and other water-harvesting structures can store rainfall and improve water availability during dry periods.

7. Drainage Management: Proper field drainage is important in areas receiving intense rainfall.

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Drainage channels can remove excess water and reduce waterlogging.

8. Supplemental Irrigation: Where water is available, small amounts of irrigation during critical dry periods can help maintain crop establishment and prevent seedling mortality.

9. Weather-Based Farm Decisions: Farmers can use weather forecasts and advisories to decide sowing, irrigation and other field operations according to expected rainfall.

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Role of Conservation Agriculture

Conservation agriculture practices such as minimum soil disturbance, residue retention and soil cover can improve soil structure and water infiltration. These practices help reduce runoff and erosion during heavy rainfall while improving moisture conservation during dry periods.

Integrated water management is also important. Combining rainwater harvesting, efficient irrigation, suitable drainage and soil-moisture conservation can make cropping systems more resilient to rainfall variability.

Economic Impact

Poor crop establishment may reduce plant population and final yield. Farmers may need to purchase additional seed for re-sowing, spend more on irrigation or incur losses when a crop fails. Uneven crop stands also make later operations such as weeding, fertilizer application and harvesting less efficient. Therefore, erratic rainfall can increase production costs and reduce farm income.

Conclusion

Erratic rainfall is a major constraint to successful crop establishment, especially in rainfed agriculture. Both excess rainfall and insufficient rainfall can affect germination, seedling emergence, root development and plant survival. The effects can be reduced through timely sowing, suitable varieties, good seed quality, proper land preparation, soil-moisture conservation, drainage, rainwater harvesting and supplemental irrigation where possible.

Improving crop establishment is essential for achieving a uniform plant population and stable crop production. Climate-smart and water-efficient agricultural practices can help farmers manage rainfall variability and reduce the risks associated with irregular rainfall.

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Climate Change and Indian Agriculture: Impacts, Vulnerability and Pathways towards Climate-Resilient Farming

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Climate change is emerging as a major challenge to the productivity, sustainability and food security of Indian agriculture. Increasing temperatures, changing rainfall patterns, prolonged dry spells, droughts, floods, heat waves and other extreme weather events are influencing crop growth, water availability, soil health and agricultural production across different agro-climatic regions of India. This paper reviews the major pathways through which climate variability and change affect Indian agriculture, with particular emphasis on temperature and heat stress, rainfall variability, extreme events, water resources and crop-specific vulnerability. Major crops including rice, wheat, millets, pulses, sugarcane and horticultural crops are discussed in relation to their sensitivity to changing temperature and moisture conditions. The paper also highlights the increasing importance of efficient irrigation, rainwater harvesting, groundwater management, soil-health improvement, crop diversification and climate-resilient crop varieties. Climate-smart agricultural practices, including conservation agriculture, integrated nutrient and pest management, agroforestry, weather-based agrometeorological advisories and improved risk-management mechanisms, can strengthen the resilience of farming systems. Recent developments in digital agriculture, remote sensing, artificial intelligence and climate information services provide additional opportunities for improving farm-level decision-making. Since climate impacts differ considerably among crops and regions, adaptation strategies need to be location-specific and integrated with local agro-ecological conditions and farmer knowledge. Strengthening collaboration among agricultural research institutions, meteorological services, extension agencies and farming communities will be essential for building resilient and sustainable agricultural systems. A coordinated approach combining climate-resilient technologies, efficient natural-resource management and timely climate information can contribute significantly to long-term agricultural productivity, livelihood security and food security in India.

1. Introduction

Climate change has emerged as one of the major challenges to agricultural productivity, natural-resource management and food security in India. Agriculture is strongly influenced by temperature, rainfall, soil moisture, atmospheric carbon dioxide (CO_2) and the occurrence of extreme weather events. Increasing temperatures, changing monsoon behaviour, heat waves, droughts, floods and intense rainfall events can alter crop phenology, water requirements, pest and disease dynamics and final yield. The effects are highly location- and crop-specific, making locally appropriate adaptation increasingly important. The IPCC identifies South Asian agriculture as particularly vulnerable to increasing heat, rainfall variability, drought and other climate extremes.

Recent evidence indicates that climate risks in India are becoming more complex because drought and excessive rainfall can occur within the same agricultural season or even within the same region. Changes in the spatial and temporal distribution of monsoon rainfall are therefore often more important for agriculture than changes in seasonal rainfall totals alone.

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2. Major Impacts of Climate Change on Indian Agriculture

2.1 Temperature and Heat Stress

Rising temperatures directly influence crop growth and development by accelerating phenological processes and increasing evapotranspiration. Heat stress during flowering and grain filling is particularly important. Wheat is highly sensitive to terminal heat, while rice, maize and several horticultural crops may also experience yield and quality losses when temperatures exceed crop-specific thresholds. Higher temperatures can additionally increase irrigation demand and influence pest and disease development.

The vulnerability of wheat-growing areas is of particular concern because warming can shorten the grain-filling period. Recent research on climate-resilient wheat production in India emphasizes adjustments in crop management, improved varieties and resource-efficient practices as important components of adaptation.

2.2 Rainfall Variability, Drought and Floods

The Indian monsoon determines the water availability of a large proportion of agricultural land. Delayed monsoon onset, prolonged dry spells or uneven rainfall distribution can reduce crop establishment and yield, particularly in rainfed farming systems. Conversely, intense rainfall over short periods can cause flooding, waterlogging, soil erosion and nutrient losses.

Recent assessments indicate considerable spatial differences in monsoon trends across India, highlighting the need for district- and agro-climatic-zone-specific climate-risk assessment rather than relying only on national averages.

2.3 Extreme Weather Events

Heat waves, droughts, floods, cyclones and intense rainfall events can cause sudden crop and infrastructure losses. Coastal agricultural areas face additional risks from cyclones, salinity intrusion and waterlogging. Horticultural crops and perennial plantations may be particularly vulnerable because damage to trees and plantations can have longer-term economic consequences.

3. Impacts on Major Crops

Rice production is sensitive to temperature, water availability and rainfall variability. Elevated CO_2 may enhance photosynthesis in C_3 crops, but this potential benefit can be reduced by heat stress, water limitations, nutrient constraints and extreme events. The IPCC reports substantial potential reductions in rice production under increasing temperature scenarios in India, although the magnitude varies among locations, crops and models.

Wheat is especially vulnerable to terminal heat stress. Timely sowing, heat-tolerant varieties, efficient irrigation, conservation agriculture and improved nutrient management can help reduce climate-related losses.

Millets and pulses have an important role in climate-resilient agriculture because several millet species can tolerate relatively dry conditions and pulses contribute to soil fertility through biological nitrogen fixation. Crop diversification involving millets, pulses and oilseeds can therefore reduce dependence on climate-sensitive crops.

Horticultural crops such as mango, banana, citrus, grape, potato and onion are sensitive to temperature, rainfall, humidity and extreme events. Changes in temperature can influence flowering, fruit setting, maturity, quality and pest incidence. Climate-based crop zoning and protected cultivation can help manage some of these risks.

4. Water Resources and Soil Management

Water availability is becoming a critical constraint for Indian agriculture. Groundwater has historically buffered farmers against rainfall variability, but declining water tables and increasing extraction costs create additional risks. Recent research has highlighted the importance of groundwater

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management and the need to address water-intensive agricultural production systems.

Efficient irrigation methods such as drip and sprinkler irrigation, improved irrigation scheduling, mulching, farm ponds, watershed development and rainwater harvesting can improve water-use efficiency. Soil-health management is equally important because soils with better organic matter and structure generally have improved water-holding capacity and resilience to drought.

5. Climate-Resilient Agriculture: Emerging Approaches

Climate-resilient agriculture should integrate productivity, adaptation, resource conservation and, where feasible, greenhouse-gas mitigation. Important measures include:

- adoption of heat-, drought- and flood-tolerant crop varieties;
- adjustment of sowing and harvesting dates;
- diversification toward millets, pulses and oilseeds;
- conservation agriculture and residue management;
- drip and sprinkler irrigation;
- rainwater harvesting and groundwater recharge;
- integrated nutrient and soil-health management;
- integrated pest and disease management;
- agroforestry and diversified farming systems;
- weather-based agrometeorological advisories;
- crop insurance and other risk-management mechanisms; and
- use of remote sensing, GIS, artificial intelligence and digital decision-support tools.

Recent Indian research emphasizes that climate-resilient agriculture must be location-specific and supported by appropriate technologies, farmer knowledge, institutional coordination and reliable climate information.

India has also increased emphasis on developing and disseminating climate-resilient crop varieties. In 2024, ICAR introduced more than 100 new crop varieties designed to address stresses such as temperature variability, water limitation, diseases and other climate-related constraints. More recently, ICAR and its partners have strengthened climate-resilience initiatives through the Atlas of Climate Adaptation in Indian Agriculture and the National Innovations in Climate Resilient Agriculture programme.

Low-carbon agricultural practices provide an additional pathway by combining improved soil, nutrient and water management with reduced greenhouse-gas emissions. Recent research indicates that such practices can contribute simultaneously to climate resilience and food security.

6. Conclusion

Climate change is reshaping the risk environment of Indian agriculture through rising temperatures, changing monsoon patterns, water stress and increasing exposure to extreme weather events. The consequences differ among crops, regions and farming systems; therefore, a uniform adaptation strategy is unlikely to be adequate. India needs integrated and location-specific approaches combining climate-resilient varieties, efficient irrigation, soil-health management, crop diversification, conservation agriculture, weather-based advisories, digital technologies and improved risk-management systems. Strengthening the connection among agricultural research, meteorological services, extension agencies and farmers will be essential for translating climate information into timely farm-level decisions. A transition toward climate-resilient and resource-

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efficient agriculture can support long-term productivity, livelihood security and sustainable food production under a changing climate.

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Geospatial Technologies for Precision and Sustainable Agriculture: Integrating Remote Sensing, GIS, UAVs and Artificial Intelligence

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Agriculture is facing increasing challenges from climate variability, declining natural resources, soil degradation, water scarcity, labour shortages and rising production costs. At the same time, increasing food demand requires agricultural systems to become more productive, efficient and sustainable. Geospatial technologies provide an effective scientific framework for addressing these challenges by generating spatially explicit, timely and multi-temporal information for agricultural decision-making. Remote sensing, Geographic Information Systems (GIS), Global Navigation Satellite Systems (GNSS), unmanned aerial vehicles (UAVs), proximal sensors, Internet of Things (IoT), cloud computing and Artificial Intelligence (AI) are transforming conventional agricultural practices into data-driven precision agriculture.

Remote sensing provides valuable information on crop growth, vegetation condition, soil characteristics, water availability, crop stress, pests and diseases, while GIS enables the integration, analysis and visualization of these diverse datasets. Satellite platforms provide repeated observations over large agricultural regions, whereas UAVs offer very high-resolution information at the field and plant scales. The integration of these technologies with machine learning and deep learning has expanded their applications from simple mapping and monitoring to prediction and decision support.

Recent developments in geospatial foundation models are creating new opportunities for agricultural applications, particularly in crop classification, segmentation and change detection. However, challenges related to data quality, model transferability, computational requirements, affordability, digital literacy, interoperability and field validation remain. Therefore, geospatial technologies should be integrated with field observations, agronomic knowledge and farmer participation. Their effective application can contribute significantly to precision, climate-smart and sustainable agriculture.

1. Introduction

Agricultural fields are characterized by considerable spatial and temporal variability in soil fertility, moisture, crop growth, nutrient requirements, pest incidence and yield. Conventional agricultural management often applies uniform quantities of seed, fertilizer, irrigation water and crop-protection chemicals across an entire field. Such practices may result in inefficient resource utilization and increased production costs. Precision agriculture addresses this limitation by identifying spatial variability and applying inputs according to site-specific requirements.

Geospatial technologies have become an important component of precision agriculture. The integration of remote sensing, GIS, GNSS, UAVs and field sensors allows agricultural information to be collected and analysed at different spatial and temporal scales. Satellite remote sensing provides repeated observations over large areas, while UAV platforms can provide centimetre-level imagery for individual fields. GIS provides an integrated environment for combining satellite imagery with

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soil, weather, topographic, crop and field-boundary information.

2. Remote Sensing and GIS Applications

Remote sensing has become an important tool for monitoring agricultural crops and natural resources. Satellite imagery can provide information on vegetation condition, crop development, soil properties, water availability and crop stress. High-resolution satellite missions have further increased the usefulness of remote sensing for precision agriculture.

Sentinel-2 imagery, for example, provides useful combinations of spatial, spectral and temporal information for crop monitoring. Vegetation indices derived from remotely sensed data can be integrated with GIS-based soil, rainfall, elevation and irrigation information. This integration can support the identification of management zones and the development of prescription maps for variable-rate application of fertilizers, irrigation water and crop-protection inputs.

GIS also supports agricultural planning at regional and farm scales. Spatial databases can integrate crop maps, soil resources, rainfall, topography, irrigation infrastructure and other agricultural information. Such integrated datasets can support crop acreage estimation, drought monitoring, crop-condition assessment, yield estimation, land-use planning and agricultural resource management.

3. UAVs and Advanced Sensors

UAV technology has significantly improved field-level agricultural monitoring. UAV-mounted RGB, multispectral, hyperspectral and thermal sensors can provide detailed information about crop canopy characteristics, plant health, water stress and nutrient deficiencies. Their high spatial resolution makes them particularly useful for detecting within-field variability.

Hyperspectral sensing is also gaining importance because its numerous narrow spectral bands can provide detailed information about crop biochemical and biophysical characteristics. The combination of UAV imagery with cloud-based geospatial processing provides opportunities for rapid crop mapping and monitoring, including applications relevant to smallholder farming systems.

4. Artificial Intelligence and Geospatial Foundation Models

Artificial Intelligence is increasingly being integrated with geospatial datasets to improve agricultural analysis and decision-making. Machine-learning algorithms such as random forests, support vector machines and gradient boosting can be applied to crop classification and estimation of soil and crop characteristics. Deep-learning approaches, including convolutional neural networks and transformer-based models, are increasingly being investigated for image classification, image segmentation, disease detection and yield prediction.

A further development is the emergence of geospatial foundation models trained using large Earth-observation datasets. Such models have the potential to provide transferable representations for several agricultural applications, including crop segmentation and change detection. Recent research has investigated models such as Prithvi, SpectralGPT and SatMAE for agricultural applications. However, model performance may decline when models are transferred to geographically different regions. Therefore, regional validation and representative training datasets remain essential.

5. Contribution to Sustainable Agriculture

The major value of geospatial technology is not simply the production of maps but the conversion of spatial information into actionable agricultural decisions. Integration of remote sensing, GIS, UAVs, IoT and AI can support variable-rate fertilization, irrigation scheduling, crop forecasting, pest and disease management and climate-risk assessment.

These technologies also have increasing relevance for developing countries and smallholder farmers.

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Open satellite data, mobile applications, cloud platforms, small UAVs and service-based technology models may improve access to precision agriculture. Nevertheless, affordability, technological accessibility, connectivity, digital literacy and farmer adoption remain important considerations.

6. Future Perspectives and Conclusion

The future of agricultural geospatial technology is likely to be characterized by closer integration of Earth observation, GIS, UAVs, IoT, cloud computing, AI and geospatial foundation models. These technologies can provide increasingly rapid and automated information for agricultural decision-making.

However, successful implementation requires reliable data, field validation, interoperability, affordability, privacy protection and locally relevant models. Technology should therefore complement rather than replace agronomic expertise, field observations and farmer knowledge.

Overall, geospatial technologies provide a strong scientific foundation for developing precision, climate-smart and sustainable agricultural systems. Their long-term contribution will depend on the ability to transform complex spatial information into affordable, understandable and locally relevant recommendations. Integrating technological innovation with agronomic knowledge and farmer participation can support more efficient use of water, fertilizers and other agricultural resources while improving the resilience and sustainability of farming systems.

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Crop Establishment Methods and Productivity of Forage Crops

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Forage crops play a pivotal role in livestock production, soil health maintenance, and sustainable agricultural systems. The productivity and nutritive quality of forage crops depend significantly on the choice of crop establishment methods, which influence seed germination, root development, nutrient uptake, and weed suppression. Traditional establishment techniques, such as conventional tillage and broad broadcasting, are increasingly being complemented or replaced by conservation agriculture practices, such as zero-tillage, minimum tillage, line sowing, and intercropping. This review provides a comprehensive analysis of various crop establishment methods across major annual and perennial forage species, evaluating their impact on dry matter yield (DMY), water-use efficiency, labor requirements, and economic returns. Proper establishment combined with site-specific agronomic management ensures optimum crop canopy density, maximizes productivity per unit area, and enhances system resilience against climate variability.

Introduction

Forage production forms the backbone of global livestock management, providing essential roughage, protein, and micro-nutrients required for optimal milk and meat output. However, global fodder supply faces growing challenges due to land degradation, climate change, water scarcity, and competing demands from food and cash crops. Enhancing forage productivity per unit area and time is therefore critical.

Crop establishment is one of the most vital stages in the agronomic lifecycle of forage crops. Small-seeded forages (e.g., berseem, alfalfa, styles) and fast-growing biomass grasses (e.g., Napier grass, fodder sorghum, maize) require specific seedbed environments and sowing depths to achieve rapid, uniform emergence. Poor establishment leads to uneven stand density, high weed competition, sub-optimal light interception, and significantly lower dry matter yield.

Selecting an appropriate establishment strategy depends on:

- **Soil Characteristics:** Texture, moisture retention, structure, and tilt.
- **Crop Type:** Seed size, vegetative propagation needs, and initial growth rate.
- **Resource Availability:** Water supply, farm machinery, labor, and budget.
- **Environmental Conditions:** Rainfall patterns, temperature, and seasonal constraints.

Classification of Crop Establishment Methods

1. Conventional Tillage and Seedbed Preparation

Conventional establishment involves primary tillage (plowing) followed by secondary tillage (harrowing and planking) to achieve a fine, weed-free seedbed.

- **Broadcasting:**
  - Seeds are scattered manually or mechanically over the field surface, followed by light planking or raking.

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- *Best suited for:* Small-seeded forages like Berseem (*Trifolium alexandrinum*), Lucerne (*Medicago sativa*), and Shaftal.
- *Advantages:* Simple, fast, and requires no specialized drilling equipment.
- *Limitations:* Non-uniform sowing depth, poor seed-to-soil contact, high seed rate requirements, and increased weed competition.

- **Line Sowing / Row Drilling:**
- Seeds are placed at uniform depths and row spacing using seed drills or manual furrowing.
- *Best suited for:* Fodder Maize, Fodder Sorghum, Pearl Millet, and Cowpea.
- *Advantages:* Uniform germination, optimized seed rate, easier inter-cultivation, and efficient light and nutrient utilization.

2. Conservation Tillage Practices

Conservation methods minimize soil disturbance, preserve soil organic carbon, and retain soil moisture.

- **Zero-Tillage / Direct Drilling:**
- Seeds are directly planted into undisturbed soil or previous crop residue using specialized zero-till drills.
- *Best suited for:* Winter forages (e.g., Oat, Ryegrass) planted immediately after rice or maize harvest.
- *Advantages:* Reduces land preparation costs, saves fuel and time, improves water conservation, and allows timely sowing.

- **Minimum / Reduced Tillage:**

a. Involves limited tillage operations (e.g., one pass of a rotavator) before sowing.

b. *Advantages:* Balances seedbed seed-to-soil contact while preserving soil structure and reducing energy consumption.

3. Vegetative Propagation Methods

Perennial forage grasses that produce low-viability seeds or exhibit slow seedling vigor are established vegetative using root slips or stem cuttings.

- **Root Slip Planting:**
- Mature root crowns or tillers with roots attached are planted directly into moist soil.
- *Best suited for:* Hybrid Napier grass (*Pennisetum purpureum* \times *P. glaucum*), Guinea grass, and Rhodes grass.
- **Stem/Cane Cuttings:**
- Stems with 2–3 active nodes are planted vertically or inclined into ridges or flat beds.
- *Best suited for:* Hybrid Napier and Para grass.

4. Special & Advanced Establishment Systems

- **Paddy Stubble/Relay Sowing (Paira/Utera Cropping):**
- Seeds of leguminous forages (e.g., Lathyrus, Berseem) are broadcasted into standing rice crops shortly before harvest.
- *Advantages:* Utilizes residual soil moisture, eliminates seedbed preparation costs, and provides early forage yield.
- **Intercropping and Mixed Cropping:**
- Simultaneous cultivation of cereal + legume forages (e.g., Fodder Sorghum + Cowpea or Oats + Mustard/Vetch).
- *Advantages:* Higher total forage biomass, enhanced forage quality (balanced crude protein and energy), atmospheric nitrogen fixation, and weed suppression.

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Factors Influencing Establishment and Productivity

Agronomic Variable	Key Requirement / Strategy	Impact on Productivity
Sowing Depth	Small seeds: 1.0–2.0 cm Large seeds: 3.0–5.0 cm	Prevents seedling exhaustion before emergence; ensures adequate moisture contact.
Seed Rate & Spacing	Specific to crop type (e.g., Maize: 50–60 kg/ha; Berseem: 25–30 kg/ha)	Maintains optimum plant population without overcrowding or canopy shading.
Seed Treatment	Rhizobium inoculation for legumes; fungicide treatment for cereals	Enhances biological nitrogen fixation and protects against seed/soil-borne diseases.
Moisture Management	Pre-sowing irrigation or planting in field-capacity soil	Critical for rapid seed germination and early root elongation.

Productivity of Major Forage Crops

Productivity in forage production is typically evaluated through **Green Fodder Yield (GFY)**, **Dry Matter Yield (DMY)**, and **Crude Protein (CP) content**.

1. Perennial Forage Grasses

- **Hybrid Napier Grass:**

a. *Establishment:* Root slips planted at 60 \times 60\text{ cm} or 90 \times 60\text{ cm}.

b. *Yield Potential:* Green Fodder Yield: **150 – 300 t/ha/year** (across 6–8 cuts); Dry Matter Yield: **30 – 50 t/ha/year**.

- **Guinea Grass & Rhodes Grass:**

(1999) *Establishment:* Seeds or root slips on well-drained soils.

(2000) *Yield Potential:* Green Fodder Yield: **80 – 150 t/ha/year**; Dry Matter Yield: **15 – 25 t/ha/year**.

2. Annual Cereal Forages

- **Fodder Sorghum & Maize:**

○ *Establishment:* Line sowing with seed drill (30\text{ cm} row spacing).

○ *Yield Potential:* Green Fodder Yield: **45 – 70 t/ha/cut**; Dry Matter Yield: **10 – 16 t/ha/cut**.

- **Fodder Oats:**

a. *Establishment:* Line sowing or broadcasting in autumn/rabi season.

b. *Yield Potential:* Green Fodder Yield: **50 – 80 t/ha** (across 2–3 cuts); Dry Matter Yield: **9 – 14 t/ha**.

3. Leguminous Forages

- **Berseem (Egyptian Clover):**

○ *Establishment:* Broadcasting in standing water (wet bed method) or dry sowing.

○ *Yield Potential:* Green Fodder Yield: **60 – 100 t/ha** (across 5–6 cuts); Dry Matter Yield: **8 – 14 t/ha**. Crude protein content ranges from 18% to 22%.

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- **Lucerne (Alfalfa):**
  - *Establishment:* Line sowing on raised ridges or flat beds (25–30\text{ cm} spacing).
  - *Yield Potential:* Green Fodder Yield: **70 – 120 t/ha/year**; Dry Matter Yield: **12 – 20 t/ha/year**. Multi-cut perennial (lasts 3–5 years).

Conclusion

Selecting the appropriate crop establishment method is a key factor in maximizing the productivity, nutritional quality, and longevity of forage crops. While traditional broadcasting and conventional tillage remain widespread, adoption of line sowing, zero-tillage, and precision vegetative propagation significantly improves resource-use efficiency, seedling vigor, and total dry matter yields.

Integrating cereal-legume intercropping, optimizing sowing depth, and utilizing conservation tillage practices enhance biomass output while conserving soil moisture and reducing operational costs. Modern forage production systems must focus on context-specific establishment techniques to achieve sustainable livestock feed production amid changing climate and resource constraints.

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Effect of Natural Farming on Soil Moisture

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Soil moisture is one of the most critical factors influencing crop growth, nutrient uptake, and resilience under drought. Natural farming, including Zero Budget Natural Farming (ZBNF), has attracted attention because it aims to improve soil functioning through biological inputs, mulching, residue cover, and minimal chemical disturbance. Recent comparative studies suggest that natural farming enhances soil moisture retention—achieving post-rainy season soil moisture levels between 11.3% and 14.7%—particularly in rainfed and semi-arid systems. It achieves this by reducing surface evaporation, maintaining cooler root-zone temperatures, and improving rainfall infiltration, aggregate stability, and earthworm abundance. This review examines the physical and biological mechanisms through which natural farming affects soil moisture, summarizes recent empirical evidence, and highlights its agronomic significance for crop germination, nutrient uptake, and yield stability. The overall conclusion is that natural farming functions as an effective moisture-conserving system rather than merely a low-input production method.

Soil Moisture and Farming Systems

Soil moisture refers to the water held in soil pores and available to plant roots. Its availability depends on rainfall, infiltration, evaporation, drainage, organic matter, soil texture, and management practices. In farming systems with bare soil exposure, moisture is quickly lost through evaporation and runoff. In contrast, systems that maintain residue cover or mulch can slow this loss and keep the upper soil layers moist for longer periods .

Natural farming is closely aligned with this moisture-conserving logic. By keeping soil covered with plant residues or biomass mulch, it reduces the impact of direct sunlight and wind at the surface. It also improves rainfall capture by reducing crust formation and encouraging infiltration into the root zone. These effects are especially important in dry spells, when small but meaningful moisture savings can sustain crop growth between rainfall events .

Mechanisms of Improvement

The most immediate mechanism by which natural farming affects soil moisture is surface mulching. Mulch acts as a physical barrier that limits evaporative losses and moderates soil temperature. Cooler soil generally retains water longer and reduces stress on roots and microbes . In studies of natural farming and mulching, the covered plots consistently showed higher moisture content than bare or conventionally managed plots.

A second mechanism is improved soil structure. Natural farming often increases organic matter inputs, which can enhance aggregate stability and create a more porous soil matrix. Better aggregation improves infiltration and water storage while reducing surface sealing and runoff . Over time, this can increase the soil's capacity to function like a sponge, storing water after rainfall and releasing it gradually to plants.

A third mechanism is biological activity. Soil microorganisms and earthworms thrive better under moderated temperature and moisture conditions, and their activity helps maintain stable pores and organic

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binding agents. In the SE India study, the higher moisture content under Zero Budget Natural Farming was associated with cooler soil and greater earthworm abundance, suggesting that biological and physical improvements occurred together . This is important because moisture retention is not only a physical property; it is also part of a living soil system.

Evidence From Recent Studies

The strongest recent evidence comes from comparative field studies of natural farming and conventional systems. In a multi-farm experiment across six districts in southeast India, Zero Budget Natural Farming plots showed higher soil moisture content than both organic and conventional plots, and the authors attributed this to mulching and the resulting cooler soil environment . The same study reported that the moisture benefit varied by district and crop, which suggests that local climate and soil conditions strongly influence outcomes .

Further support comes from studies specifically examining mulching within natural farming. A 2025 paper on natural farming and mulching synergies reported that mulching improves moisture conservation, regulates soil temperature, suppresses weeds, and enriches soil organic carbon. Similarly, a study on maize under ZBNF reported that soil moisture was markedly higher in the post-rainy season when paddy straw mulch was used, with moisture values ranging from 11.3 to 14.7%. These findings reinforce the idea that mulch is one of the most effective moisture-saving components of natural farming.

Evidence from broader organic mulch literature also supports the same pattern. Organic mulches are widely reported to improve moisture retention, especially in rainfed conditions, by reducing surface evaporation and improving rain infiltration. While not all of these studies are strictly about natural farming, they help explain why natural farming systems that rely on residue cover often show better moisture performance than bare-soil or heavily tilled systems.

Agronomic Significance

Improved soil moisture has direct consequences for crop productivity. When the root zone stays moist for longer, seeds germinate more uniformly, roots explore the soil more effectively, and nutrient uptake becomes more consistent. Moisture conservation can also reduce the need for irrigation, which is valuable for smallholders operating under water constraints [1][3]. In practical terms, natural farming may not eliminate drought stress, but it can reduce its severity and duration.

Moisture benefits also contribute to yield stability. The SE India experiment found that yield was higher under ZBNF than under conventional or organic treatments, and the authors linked part of that advantage to better soil moisture and mulch-driven cooling . This is important because it suggests that soil water conservation is not an isolated outcome but part of a wider productivity effect. In systems where rainfall is unpredictable, even modest moisture gains can translate into meaningful agronomic returns .

Table containing important parameters of effect of naturalfarming on soil moisture

Parameter	**Category**	**Primary mechanism**	**Observed outcome/impact**
Volumetric Soil Moisture Content (%)	Physical Hydrology	Residue and straw mulching create a physical barrier, slowing surface water loss.	Reached **11.3% to 14.7%** in post-rainy season ZBNF maize using paddy straw mulch.

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Soil Temperature (°C)	Microclimate / Physical	Surface shading reduces direct solar radiation and wind impact.	Maintains cooler root-zone environments during periods of high evapotranspiration demand.
Infiltration Rate & Water Capture	Physical Hydrology	Prevention of surface sealing and raindrop-induced soil crusting	Improves rainfall capture into the root zone and reduces surface runoff losses.
Soil Aggregate Stability & Porosity	Soil Structure	Increased organic matter inputs improve soil matrix binding	Enhances the soil's sponge-like capacity to store and gradually release water.
Earthworm Abundance & Microbial Activity	Biological Indicator	Cooler, moister soil microclimates foster favorable living conditions.	Increases biological binding agents and maintains stable macropores.
Germination & Nutrient Uptake	Agronomic Performance	Prolonged root-zone moisture availability during dry spells	Promotes uniform seed germination, deeper root exploration, and steady nutrient uptake.
Crop Yield Stability	Agronomic Output	Integrated effect of lower root stress, increased moisture retention, and soil cooling.	ZBNF produced higher crop yields compared to organic and conventional systems in rainfed conditions.

Conclusion

Natural farming can improve soil moisture through a combination of mulch cover, reduced evaporation, enhanced infiltration, better aggregation, and stronger biological activity . The evidence suggests that mulch is the most immediate and visible driver of moisture conservation, while improved soil structure and organic matter build longer-term resilience .In water-limited agriculture, these effects make natural farming an important soil moisture management strategy. Its value lies not only in reducing input dependence but also in helping the soil store and use rainfall more efficiently .

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Insect Pests of Maize: Importance, Damage Symptoms and Management Strategies

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Maize (Zea mays L.) is one of the most important cereal crops cultivated worldwide for food, feed, and industrial purposes. It contributes significantly to food security and agricultural economies. However, maize production is severely affected by several insect pests throughout its growth stages, resulting in substantial yield losses and reduced grain quality. Among these pests, fall armyworm, stem borers, shoot flies, aphids, and cutworms are considered major constraints to maize cultivation. The severity of pest infestation depends on climatic conditions, cropping systems, and agronomic practices. Effective pest management requires an integrated approach involving cultural, biological, mechanical, and chemical methods. This article reviews the major insect pests of maize, their biology, nature of damage, and sustainable management practices for improving maize productivity.

Introduction

Maize (Zea mays L.) is the third most important cereal crop worldwide after rice and wheat. It grows in a wide range of agro-climatic conditions due to its higher productivity and multipurpose uses. The grains of maize are used as food, feed, and fodder, while its various products are used as raw materials in different industries like starch, ethanol, and biofuel production.

However, maize is highly susceptible to attack by insect pests at all developmental stages, starting from seedling to maturity. More than 140 species of insects have been reported to damage maize plants globally, among which few are of economic importance. These insect pests destroy almost all the parts of maize plants, causing severe yield loss.

Recently, fall armyworm (Spodoptera frugiperda) has emerged as a serious threat to maize production in many countries, including India. Hence, the current research focuses on the biology, damage symptoms, and management of maize insect pests.

Major Insect Pests of Maize

1. Fall Armyworm (*Spodoptera frugiperda)*

Distribution and Importance

Fall armyworm (FAW) is an invasive pest native to the Americas

and has become one of the most destructive pests of maize

worldwide. Since its first detection in India in 2018, it has spread

rapidly across maize-growing regions.

Identification

- Eggs are laid in clusters covered with scales.
- Larvae vary from greenish to dark brown.
- Mature larvae possess an inverted "Y" mark on the head capsule.
- Four black spots arranged in a square pattern are visible

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on the eighth abdominal segment.

Nature of Damage

- Young larvae scrape leaf tissues causing window-pane damage.
- Older larvae feed aggressively on leaf whorls.
- Severe infestation results in ragged leaves with large holes.
- Larvae may attack tassels and developing cobs.

Yield Losses

Yield losses ranging from 15–70% have been reported depending on infestation severity and crop stage.

Management

- Timely sowing.
- Installation of pheromone traps.
- Conservation of natural enemies.
- Application of biopesticides such as Bacillus thuringiensis.
- Use of recommended insecticides when economic threshold levels are exceeded.

2. Maize Stem Borer (*Chilo partellus)*

Importance

Stem borers are among the most destructive pests of maize in Asia and Africa. Chilo partellus is the predominant species attacking maize.

Identification

- Adult moths are straw-colored.
- Eggs are laid in overlapping masses.
- Larvae are creamy-white with brown heads.

Nature of Damage

- Young larvae feed on leaves producing pinholes.
- Larvae bore into stems causing internal damage.
- Dead-heart symptoms occur when central shoots are destroyed.
- Tunneling weakens plants and reduces nutrient transport.

Management

- Removal of crop residues.
- Early sowing.
- Use of resistant hybrids.
- Release of parasitoids such as Trichogramma spp.
- Need-based insecticide application.

3. Shoot Fly (*Atherigona spp.)*

Identification

Shoot flies are small grey-coloured flies commonly attacking maize during early growth stages.

Damage Symptoms

- Maggots bore into the central shoot.
- Central leaf dries and can be pulled out easily.

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- Dead-heart formation occurs.
- Plant population is reduced under severe infestation.

Management

- Timely sowing.
- Seed treatment with systemic insecticides.
- Maintenance of optimum plant population.
- Destruction of infested seedlings.

4. Cutworms (Agrotis spp.)

Identification

Cutworms are nocturnal caterpillars that remain hidden in soil during daytime.

Damage Symptoms

- Larvae cut seedlings at ground level.
- Plants wilt and die.
- Damage is more severe in newly emerged crops.

Management

- Deep summer ploughing.
- Field sanitation.
- Collection and destruction of larvae.
- Application of poison bait where necessary.

5. Aphids (*Rhopalosiphum maidis)*

Identification

Aphids are small, soft-bodied insects occurring in colonies on leaves and tassels.

Nature of Damage

- Sap sucking causes weakening of plants.
- Honeydew secretion promotes sooty mold growth.
- Leaves become yellow and curled.
- Aphids transmit viral diseases.

Management

- Conservation of ladybird beetles and lacewings.
- Avoid excessive nitrogen application.
- Spray neem-based formulations.
- Apply selective insecticides if infestation becomes severe.

6. Corn Earworm *(Helicoverpa armigera*)

Identification

The corn earworm is a polyphagous pest attacking maize ears and kernels.

Damage Symptoms

- Larvae feed on silks and developing grains.
- Entry holes are visible near ear tips.
- Contamination with larval excreta reduces grain quality.

Management

- Timely harvesting.
- Monitoring through pheromone traps.
- Biological control using parasitoids.
- Need-based insecticide application.

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7. White Grubs (*Holotrichia spp.*)

Identification

White grubs are C-shaped larvae of scarab beetles inhabiting the soil.

Damage Symptoms

- Feed on roots.
- Plants show wilting and stunted growth.
- Severe infestations may cause plant death.

Management

- Deep ploughing.
- Collection of adult beetles from host trees.
- Soil application of recommended insecticides.
- Crop rotation.

8. Termites (*Odontotermes spp.*)

Importance

Termites are serious pests in rainfed and drought-prone maize-growing areas.

Damage Symptoms

- Feed on roots and stem bases.
- Plants become weak and dry.
- Lodging may occur.

Management

- Seed treatment.
- Application of organic matter.
- Field sanitation.
- Soil treatment when required.

Factors Influencing Pest Incidence

Several environmental and agronomic factors influence insect pest populations in maize:

1. Climatic Conditions

Temperature, humidity, and rainfall directly affect insect development, survival, and reproduction.

2. Cropping Pattern

Continuous maize cultivation favors pest buildup by providing uninterrupted food sources.

3. Planting Time

Late-sown crops often experience higher pest infestations due to synchronization with peak pest populations.

4. Nutrient Management

Excessive nitrogen fertilization may increase susceptibility to sucking pests and caterpillars.

5. Host Plant Resistance

Genetic resistance plays an important role in reducing pest damage and dependence on insecticides.

Integrated Pest Management (IPM) in Maize

Integrated Pest Management (IPM) is an environmentally friendly strategy combining multiple pest control methods to maintain pest populations below economic injury levels.

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Cultural Control

- Timely sowing.
- Crop rotation.
- Removal of crop residues.
- Balanced fertilization.
- Proper irrigation management.

Mechanical Control

- Handpicking of egg masses and larvae.
- Installation of light traps.
- Use of pheromone traps for monitoring.

Biological Control:

Biological control is an important pest management approach in which natural enemies are used to suppress pest populations. These natural enemies are mainly classified into predators, parasitoids, and pathogens.

Predators such as ladybird beetles, green lacewings, spiders, and predatory bugs directly feed on and reduce insect pests.

Parasitoids such as Trichogramma spp., Telenomus spp., and Cotesia spp. develop on or inside their host insects and eventually kill them.

Pathogens are disease-causing microorganisms that infect and control insect pests. Important examples include the bacterium Bacillus thuringiensis (Bt), the entomopathogenic fungi Beauveria bassiana and Metarhizium anisopliae, and Nuclear Polyhedrosis Virus (NPV). Together, these natural enemies play a significant role in reducing pest populations and promoting environmentally sustainable pest management.

Botanical Pesticides

Neem-based products are effective against several maize pests and are safer for natural enemies.

Chemical Control

Chemical insecticides should be used only when pest populations exceed economic threshold levels. Proper dosage, timing, and rotation of insecticides are necessary to prevent resistance development.

Economic Impact of Insect Pests

The insect pests that destroy maize (corn) in many parts of the world result in economic loss since the yields are reduced by 10% to over 70%. This depends on the pest species, level of infestation, and control measures. In addition to reduced yield, pests also result in poor quality grain, extra costs incurred in controlling them, and poor market value of the produce.

The recent invasion of fall armyworm and other pests has further challenged farmers to control strategies to ensure they have a profitable harvest.

Future Perspectives

Advancements in pest management technologies offer promising opportunities for reducing maize pest damage. These include:

- Development of resistant maize hybrids.
- Precision agriculture and remote sensing.
- Biological control enhancement.
- RNA interference-based pest control.
- Integrated digital pest monitoring systems.
- Climate-resilient pest management strategies.

Future research should focus on eco-friendly approaches that minimize environmental impact while maintaining effective pest suppression.

Conclusion

Maize is an economically important crop that is vulnerable to attack by a host of insect pests at various developmental stages of the plant. The major insect pests of maize in the study area included fall armyworm, stem borers, shoot flies, aphids, cutworms, and termites. The most effective control

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method for insect pests of maize is through the implementation of a successful integrated pest management program that incorporates cultural, biological, mechanical, botanical, and chemical means of pest control. If properly implemented, integrated pest management will help lower the incidence of insect pests of maize while raising productivity. There is a need for more research on maize insect pests and increased awareness among farmers to help combat these pests and ensure food security.

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Breeding Better Onions: From Male Sterility and Heterosis to Genomic and Climate-Smart Breeding

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Onion (*Allium cepa* L.) is one of the most important bulb vegetables cultivated for fresh consumption, processing and trade. In India, its cultivation extends across diverse agro-climatic conditions, resulting in a wide range of production environments and varietal requirements. Increasing climatic variability, biotic stresses, fluctuations in water availability and post-harvest losses necessitate continuous genetic improvement of onion. Conventional selection and hybridization have provided the foundation for onion improvement, while cytoplasmic male sterility has facilitated the development of commercial hybrids through efficient hybrid seed production. Contemporary breeding programmes increasingly integrate heterosis breeding with molecular markers, genetic mapping, genome-wide association studies, genomic resources and precision phenotyping. Major breeding objectives include high and stable bulb yield, uniform bulb size and shape, desirable colour and pungency, high dry matter, improved storage life, resistance to pests and diseases and tolerance to drought, heat and excess moisture. Recent developments in onion genomics, including chromosome-level genome assemblies and specialized molecular marker databases, are creating new opportunities for precision breeding. The future of onion improvement will depend on integrating genetic diversity, superior parental lines, hybrid breeding, genomic information and multi-environment testing to develop productive, quality-oriented and climate-resilient cultivars.

Introduction

Onion (*Allium cepa* L.) is an economically important bulb vegetable and an integral component of food systems in many parts of the world. It is consumed fresh and processed and is valued for its characteristic flavour, pungency and diverse culinary applications. In India, onion occupies an important position among vegetable crops and is cultivated under different production seasons and agro-climatic conditions.

The productivity and quality of onion are influenced by genotype, temperature, photoperiod, moisture availability, soil conditions, pests and diseases and post-harvest handling. Bulb formation is particularly sensitive to environmental conditions and cultivars differ considerably in their adaptation to specific seasons and regions.

Consequently, genetic improvement remains a major component of sustainable onion production. Conventional breeding has contributed to the development of improved cultivars through selection and hybridization. The exploitation of cytoplasmic male sterility has further strengthened hybrid breeding by facilitating efficient production of hybrid seed.

The breeding landscape is now expanding towards molecular and genomic approaches. Recent advances in onion molecular genetics include molecular marker development, genetic mapping, QTL identification, RNA sequencing, studies of bulb colour and chemical composition and characterization of genomic regions associated with bulbing, flowering, male sterility and disease resistance. Thus, modern onion breeding is

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increasingly moving towards an integrated framework in which **genetic diversity, conventional breeding, heterosis, molecular genetics, genomics and precision phenotyping** complement one another.

Breeding Objectives in Onion

The primary objective of onion breeding is to develop cultivars that combine high and stable productivity with desirable bulb characteristics, broad environmental adaptability and superior post-harvest performance.

A major breeding objective is improvement of **bulb yield and yield stability**. In addition to yield, breeders aim to develop plants producing uniform bulbs with desirable size, shape, colour and maturity. Good skin retention is particularly important because it contributes to bulb appearance and marketability.

Pungency and flavour are also important quality attributes. Depending on the intended market, breeders may select for appropriate levels of pungency. For processing purposes, characteristics such as dry matter and total soluble solids are particularly important.

Storage quality is another major objective. Extended dormancy, delayed sprouting, high dry matter, bulb firmness and resistance to storage disorders can help reduce post-harvest losses.

Disease and pest resistance are also important targets. With increasing environmental variability, breeding programmes are placing greater emphasis on **drought tolerance, heat tolerance, excess-moisture tolerance and yield stability under stress**.

Adaptation to different planting seasons and photoperiodic conditions is particularly important in onion because bulb initiation and development are strongly influenced by environmental conditions. Therefore, contemporary onion breeding extends beyond yield improvement and encompasses **quality, storability, disease resistance, stress tolerance, processing suitability and market acceptance**.

Genetic Diversity: The Foundation of Onion Improvement

Genetic diversity is the fundamental resource for crop improvement. Onion germplasm encompasses considerable variation in bulb size, shape, colour, maturity, pungency, dry matter, storage behaviour and environmental adaptation.

Landraces, traditional cultivars, breeding populations, elite lines and specialized genetic stocks can provide valuable alleles for crop improvement. Systematic characterization of germplasm allows breeders to identify parents possessing complementary characteristics.

Germplasm evaluation should include both agronomic and quality traits. Yield, maturity, bulb characteristics, dry matter, pungency, disease response, storage behaviour and tolerance to abiotic stresses should preferably be evaluated across relevant environments.

The effective conservation and utilization of genetic diversity is particularly important for climate-smart breeding because genetic resources may contain useful variation for tolerance to drought, heat, waterlogging and other environmental stresses.

Male Sterility: The Basis of Hybrid Onion Breeding

The exploitation of **cytoplasmic male sterility (CMS)** is one of the most important developments in onion breeding. Onion is predominantly cross-pollinated and therefore has considerable potential for heterosis breeding. However, commercial hybrid seed production requires reliable prevention of self-pollination in the female parent.

CMS provides an efficient biological mechanism for achieving this objective. Male sterile plants produce non-functional pollen while retaining female fertility, allowing them to serve as female parents for hybrid seed production.

A conventional CMS-based system involves three important components:

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A line – Male-sterile female parent: The A line is cytoplasmic male sterile and does not produce functional pollen. It serves as the female parent for hybrid seed production.

B line – Maintainer parent: The B line is genetically similar to the A line but produces fertile pollen. It is crossed with the A line to maintain and multiply the male-sterile female parent.

Pollen parent – Fertile male parent: The pollen parent produces viable pollen and is crossed with the A line to produce the commercial **F_1 hybrid seed**.

The maintenance of stable male sterility and the identification of suitable pollen parents are therefore essential for successful hybrid production.

Molecular studies have further strengthened this system by providing markers associated with cytoplasmic types and fertility-restoring regions. Recent Indian research has demonstrated the usefulness of molecular markers for characterizing cytoplasm and the fertility-restoration locus in onion. Such approaches can increase the efficiency of parental selection and hybrid development.

Heterosis and Hybrid Breeding

Heterosis or hybrid vigour refers to the superior performance of a hybrid relative to its parents for one or more traits. In onion, heterosis can be exploited for improvement of yield, bulb uniformity, plant vigour, maturity and adaptation.

The identification of suitable parental combinations is a central component of hybrid breeding. Breeders evaluate parental lines for general and specific combining ability and subsequently assess promising hybrids across environments.

Indian Examples of Improved Onion Cultivars

Indian onion breeding programmes have resulted in the development of several improved cultivars with specific adaptation and quality characteristics.

ICAR-DOGR has developed varieties including **Bhima Super, Bhima Dark Red, Bhima Red, Bhima Shweta and Bhima Shubhra**, among others. Their characteristics demonstrate how breeding objectives can be combined with seasonal adaptation and market requirements.

Cultivar	Important characteristic	Breeding/production relevance
Bhima Super	Red bulb, predominantly single-centred bulbs	Adapted to kharif and late kharif production
Bhima Dark Red	Attractive dark-red flat-globe bulbs	Market-oriented bulb colour and appearance
Bhima Red	High marketable yield and storage potential	Suitable for multiple production seasons
Bhima Shweta	White bulb with suitable quality characteristics	Suitable for kharif and rabi production
Bhima Shubhra	White bulb with tolerance to environmental fluctuation	Climate-adaptation and quality improvement

For example, ICAR reports that **Bhima Super** is recommended for kharif cultivation in several states including Tamil Nadu, while **Bhima Red** has been recommended for multiple seasons and regions. Such examples illustrate that onion breeding programmes are addressing not only yield but also **seasonal adaptation, bulb colour, maturity, storage and environmental stability**.

Breeding for Bulb Quality

Bulb quality is a major determinant of market value. Important characteristics include bulb size, shape, colour, skin retention, firmness, dry matter, pungency and total soluble solids.

Uniform bulb size and shape facilitate grading and marketing. Skin colour is an important consumer and

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market preference, while pungency influences culinary quality.

For processing industries, high dry matter and suitable soluble solids are particularly desirable. Therefore, breeding programmes should evaluate quality traits alongside yield rather than treating quality as a secondary characteristic.

Selection for multiple quality traits can contribute to the development of cultivars that satisfy specific market segments, including fresh markets, dehydration industries and processing enterprises.

Breeding for Storage Life

Storage performance is an important component of onion breeding because the crop is harvested seasonally but consumed throughout the year. During storage, bulbs can undergo sprouting, moisture loss, physiological deterioration and microbial decay. These processes reduce marketable yield and economic returns.

Breeding can contribute substantially to improving the storage performance of onion through the selection and incorporation of complementary traits associated with prolonged storability. Important breeding targets include **extended bulb dormancy, delayed sprouting, high dry matter content, adequate bulb firmness and resistance to physiological and microbial storage disorders**. The combination of these traits can help maintain bulb quality for longer periods, minimize post-harvest losses and extend the marketable life of harvested onions.

Storage evaluation should therefore be integrated into breeding programmes. Genotypes should be assessed not only for field performance but also for their ability to retain bulb quality during prolonged storage. Improved storage ability can reduce post-harvest losses and extend the marketing period of the crop.

Breeding for Climate Resilience

Climate variability is emerging as an important challenge to onion production. Increased temperatures, irregular rainfall, drought, excess moisture and changing pest and disease pressures can adversely affect growth and bulb development.

Climate-resilient onion breeding should focus on the development of cultivars capable of maintaining consistent growth, bulb development and productivity under variable and stressful environmental conditions. Breeding programmes should therefore prioritize **heat tolerance, drought tolerance, tolerance to excess moisture, resistance to major diseases, stable bulb development and yield stability across environments**.

The evaluation of germplasm under contrasting environments is particularly important. A genotype performing well under favourable conditions may not necessarily maintain productivity under drought or high-temperature conditions. Multi-environment testing is therefore essential for identifying genotypes with stable performance. The development of cultivars adapted to different planting seasons is equally important because onion growth and bulb formation are strongly influenced by temperature and photoperiod.

Molecular Breeding and Marker-Assisted Selection

Conventional selection remains fundamental to onion improvement, but molecular markers can improve the precision and efficiency of selection.

Markers can be used for:

- Genetic diversity assessment
- Parental characterization
- Identification of cytoplasmic types
- Detection of fertility-restoring loci
- QTL mapping
- Marker-assisted selection

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- Genetic identification of breeding lines

Recent reviews indicate substantial progress in the molecular genetics of onion, including characterization of genes and pathways involved in bulb colour, chemical composition, bulbing, flowering, vernalization, disease resistance and male sterility.

The use of molecular markers is particularly relevant to hybrid breeding because breeders can characterize parental lines before extensive field testing.

QTL Mapping and GWAS

Many economically important onion traits are quantitatively inherited. Yield, bulb size, maturity, storage behaviour and stress tolerance may be controlled by multiple genes and influenced by environmental conditions. **QTL mapping** enables breeders to identify genomic regions associated with quantitative traits. **Genome-wide association studies (GWAS)** provide an alternative approach by examining associations between genetic markers and traits in diverse populations.

The integration of QTL mapping, GWAS and phenotypic evaluation can facilitate the identification of genomic regions associated with important traits.

The information generated through these approaches can subsequently support marker-assisted selection and genomic prediction.

Genomic Resources for Next-Generation Onion Breeding

The large and repeat-rich onion genome has historically presented challenges for molecular research. However, advances in sequencing technologies are rapidly improving genomic resources.

A chromosome-level reference genome of the doubled-haploid onion line **DHW30006** was reported with a **12.77 Gb assembled genome**, 65,730 predicted gene models and eight pseudo-chromosomes. The resource was generated using PacBio, Illumina and Hi-C sequencing approaches and provides an important foundation for biological research and molecular breeding.

Such genomic resources can facilitate gene discovery, marker development and identification of genomic regions associated with agronomically important traits.

Another important recent development is the **Onion SSR Database**, launched by ICAR-DOGR, Pune on 27 March 2026. ICAR highlighted the database as a resource for strengthening molecular research and integrating molecular tools with conventional onion breeding.

These developments demonstrate the rapid transition of onion breeding towards a data-supported and genomics-assisted framework.

Precision Phenotyping and Digital Breeding

Genomic selection and molecular breeding require reliable phenotypic information. Conventional phenotyping can be time-consuming and may involve observer variation. Precision phenotyping technologies can provide objective measurements of plant and bulb characteristics. Imaging systems, sensors and automated data acquisition can be used to assess traits such as plant growth, canopy development, bulb size, bulb shape and colour.

Climate-resilient onion breeding should focus on the development of cultivars capable of maintaining consistent growth, bulb development and productivity under variable and stressful environmental conditions. Breeding programmes should therefore prioritize **heat tolerance, drought tolerance, tolerance to excess moisture, resistance to major diseases, stable bulb development and yield stability across environments**.

The integration of these traits into superior genetic backgrounds can enhance the adaptability of onion cultivars to changing climatic conditions and reduce fluctuations in productivity.

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From Conventional Breeding to Precision Onion Breeding

The transition towards genomic breeding should not be viewed as a replacement for conventional breeding. Rather, both approaches should be integrated. Conventional breeding remains essential for evaluating actual field performance, combining ability, adaptation and market acceptability. Molecular and genomic tools provide additional information about the genetic constitution of breeding materials.

Integrated Framework for Onion Breeding

The integration of conventional breeding with molecular and genomic approaches provides a comprehensive framework for accelerating genetic improvement in onion. The breeding process can be conceptualized as a progressive sequence beginning with the exploitation of genetic diversity and continuing through selection of superior parental lines, development and utilization of cytoplasmic male sterility, hybrid breeding, molecular characterization and genomic analysis. Precision phenotyping and multi-environment evaluation can subsequently be used to validate the performance and stability of promising genotypes.

Such integration can improve selection efficiency and accelerate the development of superior cultivars.

Climate-Smart and Farmer-Oriented Breeding

A successful onion cultivar must perform well not only in experimental conditions but also under farmers' field conditions. Therefore, breeding objectives should incorporate farmer preferences, market requirements, storage characteristics and production constraints. The development of such cultivars requires collaboration among plant breeders, geneticists, molecular biologists, physiologists, agronomists, post-harvest specialists and farmers. A climate-smart onion cultivar should combine high productivity with stable performance, desirable bulb quality and enhanced resilience to both biotic and abiotic stresses. The ideal breeding target is therefore the integration of **high yield, yield stability, superior bulb quality, extended storage life, disease resistance, heat tolerance and drought tolerance** within a well-adapted genetic background. The integration of these traits can improve cultivar performance under variable environmental conditions while maintaining marketable bulb quality and reducing production and post-harvest losses.

Quality seed production is equally important. Even a genetically superior variety cannot realize its potential if high-quality seed is not available to farmers. ICAR field programmes have demonstrated the importance of quality seed production and farmer participation in onion improvement.

Future Prospects

The future of onion breeding will increasingly depend on the integration of genetic diversity, hybrid breeding and genomics. The development of true inbred lines, efficient CMS systems and superior pollen parents will remain important for hybrid breeding. Doubled haploid technology may accelerate the development of genetically uniform parental lines, while molecular markers can facilitate their characterization. The availability of chromosome-level genome assemblies and specialized marker databases provides additional opportunities for gene discovery and precision breeding. Genomic selection, digital phenotyping and multi-environment testing can further strengthen breeding for complex traits and yield stability. Future Breeding Pipeline for Onion Improvement

The future of onion breeding will increasingly depend on the integration of conventional breeding principles with molecular, genomic and precision phenotyping approaches. The breeding pipeline can be conceptualized as a progressive framework beginning with the identification and characterization of genetic diversity, followed by the selection of superior parental lines and development of stable CMS and maintainer lines. Heterosis breeding can then be combined with molecular characterization,

QTL mapping, GWAS and genomic prediction to enhance the precision of selection. Precision phenotyping and multi-environment validation are essential for assessing trait expression, adaptability and yield stability under diverse production conditions.

Conclusion

Onion breeding is undergoing a significant transition from conventional selection towards an integrated framework combining **genetic diversity, cytoplasmic male sterility, heterosis, molecular breeding, genomics and climate-resilience breeding**.

Conventional breeding will continue to provide the foundation for cultivar development, while molecular and genomic approaches can improve the precision and efficiency of selection. Recent advances in onion molecular genetics, the development of chromosome-level genomic resources and the establishment of specialized molecular databases are expanding the opportunities for precision breeding.

Future onion cultivars should combine **high and stable productivity, superior bulb quality, extended storage life, resistance to biotic stresses and tolerance to climatic variability**. The integration of conventional breeding with genomics, precision phenotyping and multi-environment testing will be essential for developing onion cultivars that meet the requirements of farmers, consumers and the processing industry.

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Challenges of Natural Farming in Pest and Disease Management

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1.Introduction

Agriculture in India faces major challenges in pest and disease management. In conventional farming, chemical pesticides are commonly used to control pests and diseases quickly. However, excessive use increases cost, causes pollution and reduces beneficial organisms.

Natural farming is an ecological approach that avoids synthetic chemical pesticides. It emphasizes preventive measures, ecological balance and use of locally available natural resources. Although sustainable, managing pests and diseases without chemicals is one of the most difficult aspects for farmers, especially during the transition period.

2. Pest And Disease Management In Natural Farming

In natural farming, management is not based on complete eradication, but on keeping pest population below economic threshold level.

- 1.Preventive and Cultural Methods: Crop rotation, intercropping, timely sowing, use of resistant local varieties and proper spacing.
- 2.Use of Botanical Preparations: Neem, garlic, chilli, tobacco based preparations. They are generally repellent in nature.
- 3.Biological Control:Conservation of natural enemies like ladybird beetles, spiders, dragonflies, parasitic wasps.
- 4.Farm-Made Preparations:Inputs based on cow dung, cow urine and other farm resources to improve plant health.

3. Major challenges in pest and disease management

- Slow Action and Low Immediate Effect:Botanical preparations act slowly compared to chemicals. They may not control severe outbreak immediately.
- Lack of Standardized Preparation and Dosage:No uniform standard for concentration and dosage. Effectiveness varies based on material quality and preparation method.
- Limited Knowledge and Technical Skill: Many farmers lack knowledge about pest identification, beneficial insects and correct use.
- Labour Intensive and Time Consuming:Preparation of inputs requires additional labour, time and continuous monitoring.
- Difficulty in Managing Severe Outbreaks:During heavy outbreak, natural methods alone may not be sufficient to prevent loss.
- Short Shelf Life:Most natural preparations cannot be stored long, need to be prepared fresh.
- Loss of Natural Enemies: Chemical use in neighbouring fields kills beneficial insects and disturbs ecological balance.

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4. Disease management challenges

- Lack of Effective Curative Measures: Most natural preparations are preventive.Once disease is established, limited curative options.
- Dependence on Environmental Conditions: Disease spread is influenced by temperature and humidity. In favourable weather, natural methods may fail.
- Risk of Contaminated Inputs: If not prepared hygienically, farm-made inputs may become source of pathogens.

5. Other associated challenges

- During transition period, pest population may increase initially.

- Limited access to bio-control agents like Trichoderma, Pseudomonas in rural areas.

- Difficulty in getting timely technical advice.

- Lack of crop insurance for yield loss.

- Market does not always give better price for naturally produced crops.

6. Strategies to overcome challenges

1. Adopt preventive approach – use crop rotation, trap crops, timely sowing.

2. Conserve natural enemies by maintaining border crops and flowering plants.

3. Use combined approach – integrate botanical, biological, cultural methods.

4. Learn proper identification of pests and diseases.

5. Prepare inputs with standard method and apply preventively.

6. Improve soil health as healthy plants resist pests better.

7. Maintain regular field monitoring and early detection.

8. Use community approach – group of farmers adopting together.

9. Keep proper records of pest incidence and treatments.

10. Seek guidance from extension services and scientific institutions.

7. Conclusion

Pest and disease management is one of the major challenges in natural farming. Natural methods are preventive, slow-acting, knowledge-intensive and labour-intensive. They may not always provide immediate control during severe outbreaks.

However, with proper knowledge, timely application, conservation of beneficial organisms and community-level adoption, these challenges can be gradually reduced. Success requires understanding of ecological processes, continuous learning and scientific guidance.

When implemented properly, natural farming can contribute to environmentally sustainable and economically viable pest management while reducing dependence on costly chemical inputs.

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On-Farm Production of Natural Farming Inputs

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Introduction

Natural Farming is a chemical-free farming system where all the necessary inputs like fertilizers and pesticides are prepared by the farmer himself using locally available resources.

What is On-Farm Production of Inputs?

It means instead of buying Urea, DAP, and pesticides from the shop, the farmer produces his own inputs on his farm using materials like cow dung, cow urine, jaggery, pulse flour, and leaves like neem.

This is the core concept of Zero Budget Natural Farming (ZBNF) introduced by Subhash Palekar.

Why is it important today?

1. High Cost of Chemicals Chemical fertilizer prices have increased by 300% in last 10 years.
2. Soil Degradation: Organic carbon in Tamil Nadu soils has come down to below 0.5%. Natural inputs can increase it to 2-3%.
3. Health Issues: To provide residue-free food for consumers.
4. Self-Reliance: Especially for farmers in Coimbatore region who have Desi cows, it makes farming self-sufficient.

The basic principle is: "One Desi Cow is enough for 30 acres of farming".

PRINCIPLES AND OBJECTIVES

A. Four Pillars of Natural Farming:

1. Jeevamrutha: Use of microbial culture to increase soil life.
2. Beejamrutha: Seed treatment using cow-based products to protect from diseases.
3. Acchadana (Mulching): Covering soil with crop waste to conserve moisture.
4. Whapasa (Soil Aeration): Maintaining air and water balance in soil.

B. Objectives of On-Farm Input Production:

1. To reduce the cost of cultivation by 70-80%.
2. To convert farm waste into wealth (Waste to Wealth).
3. To increase the population of beneficial microorganisms like earthworms, fungi and bacteria in the soil.
4. To make the farmer independent from external market and credit.
5. To promote sustainable and climate-resilient agriculture.

C. Requirements for Production Unit:

A small shaded area of 10x10 feet, two 200-liter plastic drums, one desi cow with its calf, and locally available leaves.

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MAJOR NATURAL INPUTS & PREPARATION - PART 1

These are liquid formulations.

1. Beejamrutha - For Seed Treatment

It protects seeds from soil-borne diseases and improves germination.

- Materials: 5 kg Desi cow dung, 5 L Desi cow urine, 50g Lime, a handful of soil from bund, 20 L water.
- Method: Mix all ingredients in 20L water and keep it overnight. Stir well. Soak seeds for 2 minutes in this solution and dry in shade before sowing.
- Usage: Any crop seeds can be treated.

2. Jeevamrutha - The Main Growth Promoter

It is a fermented microbial culture which multiplies beneficial microbes in the soil by 500 times.

- Materials: 10 kg Cow dung, 10 L Cow urine, 2 kg Jaggery, 2 kg Gram flour (Besan), 100g fertile soil, 200 L water.
- Method: Mix everything in a 200L drum. Stir clockwise 2 times a day for 3 days. It will start fermenting. Use from 3rd to 7th day. Do not store after 7 days.
- Application: Mix 200L Jeevamrutha with irrigation water for 1 acre. Apply twice a month. It is not a fertilizer, it is a bio-catalyst.

3. Neemastra & Brahmastra - Natural Pesticides

For sucking pests and big chewing pests.

- Neemastra: Crush 5 kg Neem leaves in water, add 5 L cow urine, 2 kg cow dung, and 200 L water. Ferment for 48 hours and filter. Spray. Effective for Aphids, Jassids.
- Brahmastra: Boil 10 L cow urine with leaves of Neem, Papaya, Custard apple, Datura, and Castor. Effective for borers and fruit borers.

MAJOR NATURAL INPUTS & PREPARATION - PART 2

4. Ghanajeevamrutha - Solid Form of Jeevamrutha

Since liquid Jeevamrutha cannot be stored long, this is made.

- Materials: 100 kg dry cow dung, 2 kg jaggery, 2 kg gram flour, 1 kg bund soil, little Jeevamrutha.
- Method: Mix all and make small balls and dry in shade. Can be stored for 6 months.
- Usage: 200 kg per acre at the time of sowing.

5. Panchagavya - Growth Tonic

Acts as a growth promoter and immunity booster.

- Materials: Cow dung 5kg, Cow ghee 500g, Curd 2L, Milk 3L, Cow urine 3L, Jaggery 3kg, Banana 12 nos, Tender coconut water 3L.
- Method: Mix dung and ghee and keep for 3 days. Then add other items and ferment for 7 days, stirring daily.
- Application: 3% solution (3L Panchagavya in 100L water) foliar spray during flowering stage to prevent flower drop.

6. Vermicompost & Farm Yard Compost (FYM)

Using earthworms (Eisenia fetida) to convert farm waste, dry leaves, and dung into high-quality compost in 45 days. It contains 1.5% Nitrogen, 1% Phosphorous, 1.5% Potassium.

BENEFITS, CHALLENGES, CONCLUSION

A. Comparative Economics:

Parameter Chemical Farming Natural Input Farming

Input Cost / Acre Rs. 15,000 - 20,000 Rs. 2,000 - 4,000

Soil Health Degrades every year Improves every year

Water Requirement High 25-30% Less

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Market Price Normal Price 20-30% Premium Price

B. Benefits:

1. Low cost and high profit.
2. Soil becomes soft, porous and earthworms increase.
3. Less water needed due to mulching.
4. Eligible for Government Schemes like PKVY (Paramparagat Krishi Vikas Yojana) and Tamil Nadu Govt's Organic Farming Scheme.

C. Challenges:

1. Initial Yield Drop: For first 1-2 seasons, yield may be slightly low. After soil recovery, yield increases.
2. Need for Desi Cow: Jersey cow dung is not effective as per Palekar method. Desi cow is mandatory.
3. Labour Intensive: Requires daily stirring and preparation.
4. Lack of Awareness: Many farmers don't know the exact preparation ratio.

Conclusion:

On-farm production of natural farming inputs is not just a farming technique, it is a movement to free farmers from debt and free soil from chemicals. It transforms the farmer from a consumer of company inputs into a producer of his own inputs. In the long run, it ensures sustainable agriculture, healthy food for society, and a profitable livelihood for the farmer.

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Soil Health Indicator For Evaluating Natural Farming

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Introduction

In chemical farming, yield is the only metric. In natural farming, soil health is the primary metric. A healthy soil must: Sustain productivity, regulate water and air, support biodiversity, and sequester carbon. Indicators help us quantify this over 1-3 years.

A good indicator must be: sensitive to management, easy and cheap to measure, and relevant to farmers.

2. Key Indicators – The Three Pillars

A. Physical indicators – structure & water

- **Bulk Density:** Lower = better porosity. Natural farming with no-tillage and mulching reduces it. Healthy: 1.1 – 1.4 g/cm3
- **Aggregate Stability:** % of soil aggregates that resist water breakdown. Improved by microbial glues from Jeevamrutha. Healthy: >50%
- **Water Holding Capacity (WHC):** Main benefit of mulching. Healthy: 45-60%
- **Infiltration Rate:** Measures Whapasa. Test with 6-inch ring. Healthy: 1.5-3.0 cm/hr. In Madukkarai red soils, it improves from 0.5 to 2.5 cm/hr after natural farming.
- **Visual:** Soil Color/Hardness: Dark brown, soft, crumbly soil = high humus.

B. Chemical Indicators – Nutrient & Balance

- Soil Organic Carbon (SOC): THE master indicator. Walkley-Black method. Every 1% increase stores 1.5 lakh litres water/acre. Healthy for TN: 0.8-1.5% (presently 0.3-0.6% is common)
- pH: Natural farming buffers pH naturally. Healthy: 6.0-7.5
- EC (Electrical Conductivity): Must be low as no chemical salts added. Healthy: <0.8 dS/m
- Available NPK: May be low in first year but stabilizes. Healthy: N 280-350, P 15-25, K 180-250 kg/ha
- CEC (Cation Exchange Capacity): Increases with organic matter. Healthy: >15 cmol/kg

C. Biological Indicators – Most Important for Natural Farming

These respond in 1-2 seasons, much faster than chemical tests.

- Microbial Biomass Carbon (MBC): Total living microbes. Should increase 2-3x after 2 years of Jeevamrutha. Healthy: >250 mg/kg
- Earthworm Count: Farmer's best friend. Dig 1x1x1 ft pit. Chemical field: <50/m3, Natural farm: 300-500/m3
- Soil Respiration: CO2 released by microbes. Measures activity. Healthy: 2-4 mg CO2/100g/24hr
- Dehydrogenase Activity: Total microbial oxidative activity. Very sensitive to Jeevamrutha. Healthy: >40 µg TPF/g/hr

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- Mycorrhizal Colonization: Natural farming promotes native mycorrhizae for P uptake. Healthy: >60% root colonization
- Fungal Mycelium: White web-like growth on mulch = active decomposition.

3. Assessment Methods

Farmer Field Kit (Zero Cost):

- Smell test: Earthy smell = actinomycetes present
- Earthworm count
- Infiltration ring test
- Slump test for aggregate stability
- Root depth

Lab Method (Every 6 Months):

Sample: 0-15 cm depth, 5 spots zig-zag per acre, before sowing and after harvest. Keep sample cool for biological tests.

4. Integrated Scoring Card for Natural Farming

Indicator	**Poor (0)**	**Medium (1)**	**Good (2)**
SOC %	<0.5	0.5-0.8	>0.8
Earthworms /m3	<100	100-300	>300
Aggregate Stability %	<30	30-50	>50
Soil Respiration	<1	1-2	>2
pH	<5.5 or >8.5	5.5-6.0	6.0-7.5

Total Score: 0-3= Degraded, 4-6= Recovering, 7-10= Healthy & Sustainable

5. Relevance to Madukkarai, Tamil Nadu

Your region has red sandy loam with low SOC and hard pan. Priority indicators for you are: SOC, Bulk Density, WHC, Earthworm count, and Microbial Activity. Locally available sugarcane trash mulching + native cow Jeevamrutha 200L/acre twice a month has shown best results.

6. Conclusion

Do not judge natural farming by first-year yield only. Yield may dip in transition (1-2 years) but biological indicators will improve. Long-term sustainability is proved by earthworms, SOC, and microbial activity. This proves natural farming regenerates soil, reduces cost, and builds climate resilience

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Research Gaps in Natural Farming Input Technology

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Introduction

Natural farming is a sustainable approach to agriculture that mainly uses locally available natural resources and biological processes. It reduces dependence on synthetic fertilizers and chemical pesticides while focusing on soil health, biodiversity and ecological balance.

Natural farming inputs include farmyard manure, compost, botanical extracts, biofertilizers, microbial preparations and other natural formulations. However, their preparation methods, quality, nutrient composition and effectiveness may vary. Therefore, scientific research is needed to standardize these inputs and improve their efficiency.

Identifying these research gaps is important for developing affordable, reliable and farmer-friendly natural farming input technologies.

2.Major Research Gaps in Natural Farming Input Technology

2.1 Lack of Standardization

One of the major research gaps is the lack of standardized methods for preparing natural farming inputs. Many inputs are prepared at the farm level using locally available materials. The quantity of ingredients, fermentation period, temperature, moisture level and preparation procedure may differ from farmer to farmer.

Such variation can affect the quality and effectiveness of the final product. A standardized protocol is therefore needed for important natural inputs.

Research should establish:

- Standard quantities of raw materials
- Suitable preparation methods
- Optimum fermentation conditions
- Appropriate dilution ratios
- Recommended application frequency
- Suitable storage conditions

Standardization would improve consistency and make scientific comparison between different studies easier.

2.2 Variation in Nutrient Composition

Natural farming inputs can contain different levels of nutrients depending on the materials used and the preparation process. Unlike synthetic fertilizers, where nutrient concentration is generally specified, many natural inputs have variable nutrient contents.

Research is needed to determine the concentration and availability of major and minor nutrients such as nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron and zinc.

Studies should also investigate how nutrients are released after application to soil and how environmental conditions influence nutrient availability.

Better information about nutrient composition can help develop appropriate application recommendations and prevent inefficient use of inputs.

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2.3 Limited Understanding of Microbial Communities

Many natural farming inputs depend on beneficial microorganisms for nutrient cycling and plant growth. However, the diversity, abundance and functions of microorganisms present in different preparations are not completely understood.

Advanced research using microbiological and molecular techniques is required to identify beneficial microbial populations and understand their role in soil fertility and crop productivity.

2.4 Lack of Long-Term Field Experiments

Many studies on natural farming inputs are conducted for a short period or under controlled conditions. Long-term field experiments are comparatively limited.

Long-duration studies are needed to determine their effects on:

- Soil organic carbon
- Soil fertility
- Soil microbial diversity
- Crop productivity
- Pest and disease incidence
- Water-use efficiency
- Overall soil health

Long-term research can also reveal whether the benefits remain stable over several cropping seasons.

2.5 Inconsistent Crop Response

Different crops may respond differently to the same natural input. The effectiveness can also vary according to soil type, climate, crop variety and management practices.

There is a need for crop-specific research to determine appropriate natural inputs, application methods and dosages for different crops and agro-climatic conditions.

2.6 Lack of Mechanized Preparation Technologies

Most natural farming inputs are prepared manually at the farm level. This can require considerable labour and time, particularly when large quantities are needed.

Research gaps exist in the development of:

- Small-scale preparation equipment
- Mixing and fermentation units
- Filtration systems
- Storage containers
- Low-cost processing technologies
- Mechanized application equipment

Developing appropriate technologies can improve efficiency and reduce labour requirements.

2.7 Storage and Shelf-Life Problems

Some natural farming inputs may undergo changes in microbial population, chemical composition and effectiveness during storage.

There is insufficient information regarding optimum storage conditions and shelf life for many preparations. Research should focus on suitable containers, temperature, moisture, packaging and preservation techniques.

2.8 Quality Control and Certification

Commercial availability of natural farming inputs requires reliable quality-control systems. At present, differences in preparation and composition can make it difficult to establish uniform quality.

Research is needed to develop simple and affordable quality indicators based on:

- Microbial activity
- Nutrient content
- pH
- Organic matter
- Contamination levels

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- Biological activity

Standard certification systems could also improve farmer confidence.

2.9 Lack of Dose and Application Guidelines

There is a research gap regarding the optimum quantity, timing and frequency of application of various natural inputs.

Future studies should identify suitable application rates according to crop growth stage, soil condition and environmental factors. This would help avoid both under-application and unnecessary use of inputs.

2.10 Limited Research on Pest and Disease Management

Natural farming uses several plant-based and biological preparations for pest and disease management. However, their effectiveness can vary considerably.

More scientific studies are required to determine:

- Active compounds
- Mode of action
- Target pests and pathogens
- Effective concentrations
- Application frequency
- Possible phytotoxic effects
- Compatibility with beneficial organisms

2.11 Interaction with Soil Properties

The interaction between natural inputs and different soil types is not fully understood. An input that performs well in one soil may show different results in another.

Research should examine the relationship between natural inputs and soil texture, pH, organic carbon, nutrient status, salinity and microbial activity.

2.12 Lack of Economic Evaluation

Technical effectiveness alone is not sufficient for widespread adoption. The economic feasibility of producing and using natural farming inputs needs greater attention.

Research should compare:

- Cost of preparation
- Labour requirements
- Input costs
- Crop yield
- Net returns
- Benefit-cost ratio
- Long-term economic benefits

3.Technology Development Needs

Future research should focus on developing simple, affordable and farmer-friendly technologies for the preparation, storage and application of natural farming inputs. Digital technologies can also be used to provide information on preparation methods, dosage, crop requirements and field conditions.

Sensor-based monitoring, microbial identification techniques and data-driven approaches may help improve the consistency and effectiveness of natural inputs.

4. Future Research Prioritie

The important areas for future research include:

1.Standardization of natural input preparation.

1. Identification and characterization of beneficial microorganisms.
2. Development of quality standards and certification protocols.
3. Improvement of shelf life and storage methods.
4. Development of low-cost preparation and application machinery.

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5. Crop- and soil-specific dosage recommendations.
6. Long-term evaluation of soil health and crop productivity.
7. Scientific validation of pest and disease management inputs.
8. Economic assessment of natural farming input technologies.
9. Development of scalable technologies suitable for small and marginal farmers.

Conclusion

Natural farming input technology has considerable potential for promoting sustainable agriculture and improving soil health. However, important research gaps remain in the areas of standardization, quality control, microbial characterization, dosage recommendations, storage, mechanization, long-term field validation and economic assessment. Addressing these gaps through interdisciplinary research can improve the reliability and effectiveness of natural farming inputs.

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Traditional Knowledge And Natural Farming

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Introduction

Traditional knowledge is the backbone of the agricultural system of any country. Traditional knowledge (TK) may be defined as an assemblage of unique beliefs and knowledge acquired, summarized and tested with changing generations, and continues to be in existence. It can be summed up as the innovative practices developed by the wisdom of human endeavor by monitoring and experimentation. Interestingly, since time immemorial several scientific experiments have been taken by the farmers on a trial and error basis in agriculture and allied activities to overcome the prevailing adverse social, economic and environmental adversaries of that time. Thus, over time indigenous people have developed and preserved distinct understandings, rooted in a cultural experience that guides relations between human and nature and influences the social, cultural and economic status of a community.

Traditional knowledge:

Interestingly, Traditional Agricultural Knowledge (TAK) has evolved over centuries to support livelihood. Agriculture the practice of cultivating plants and livestock is itself a tradition and is one of ever evolving practices utilizing ancient to modern technologies. Traditional Agricultural Knowledge, TAK thus involves the usage of indigenous knowledge, traditional tools, natural resources and the cultural beliefs of the farmer. A traditional knowledge based food production system may offer a possible solution for food security and sovereignty as it offers a cost effective, nature based, sustainable and environment friendly strategy. Thus, validation, revival and dissemination of Indigenous Traditional Knowledge (ITK) become important for the sustainable development of agriculture which once fed into the current research system can develop low cost and effective technologies for the benefit of the farming community.

The agriculture system in India began as early as 9000 BC. Agriculture is not only for fulfilling the present and future demands of food but it is a way of life for Indian people. Conceptually, even the present Indian agriculture system can be categorized as a partially traditional agriculture system as the majority of the farmers still follow traditional agriculture practices in one way or another. However, with the inception of new technologies in agriculture, the traditional practices are disappearing at a faster rate. Although the majority of tribal and indigenous communities in India still follow these traditional practices and play a pivotal role in preserving traditional agricultural knowledge

In this way, in addition to the conservation of natural resources, TK plays an important role in better livelihood and improvement in the socio-economic status of tribal communities involved in farming operations. Indigenous and Tribal farmers are known to have acquired rich traditional agricultural knowledge in due course of time to overcome various obstacles due to their geographical remote and extreme living habitations, adverse biotic and abiotic factors, landforms, etc. and have been successful in overcoming these effects with their

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innovative and spontaneous evolving traditional practices. Indigenous knowledge is a product of the adaptation of farming practices to the local environment, creating unique indigenous farming practices and food culture. Indigenous food cultures in Indonesia are usually rich in biodiversity, creating a demand for biodiversity agricultural products. Therefore, if the demand for these food cultures can be sustained, the agricultural biodiversity can also be preserved for generations to come, subsequently supporting food security. The diversity in ethnic, species and topography has become the basis of Indonesian traditional farming for hundreds of years.

Traditional knowledge and Natural Farming:

On the other hand, the national policy tries to increase annual agricultural production to support the national food security by means of agricultural industrialisation leading to deforestation by opening new lands in several places, putting local diversity under potential erosion, depletion and degradation. Biodiversity is one of the requirements to enrich the nutritional intake in household level in order to increase food security. This study describes the role of indigenous knowledge in traditional farming systems on natural resources management.

Natural farming is a generic term which is based on basic ecological principles. Based on the principles of natural farming, different methods of farming are prevalent in India. These methods have different constituents, scope and implementation in the present context of promotion of chemical free low-cost environment friendly agriculture.

Natural Farming has the potential to significantly reduce production expenses as it uses Jivamrita, Bijamrita, Acchadana (Mulching), and Whapasa which costs very less and are locally available. The continual retention of crop wastes replenishes soil fertility and aids in soil health maintenance. There are several benefits of covering the soil with dust or plant materials (Acchadana/ mulching). One of mulch's main advantages is that it helps to retain soil moisture. It protects the soil from erosion. Besides, it improves soil aeration and conserves soil moisture by checking evaporation water loss. Weed emergence is to some extent checked through mulching. Mulching increased soybean seed yield as well as plant biomass and nodule mass. Soil physical qualities improved as mulching rates increased. Further, organic types of mulches such as dried plants additionally produce humus on decomposition, which supplies nutrients to the crop. An ideal microclimate for microbes and local earthworms can be established through using straw mulch. In soil, organic dry matter decomposes into humic substances when buried living organisms, including plants and animals. As mulching reduces the requirement of tillage, labour shortages can be compensated. Live mulch (using different plants) is helpful as different nutrients can be added in the soil (monocots supply potassium, phosphorus etc. while dicots or legumes fix atmospheric nitrogen).

Traditional crops:

As the area is a rain-fed thus the farmers here grow traditional crops such as maize (Zea mays), pigeonpea (Cajanus cajan), black gram (Vigna mungo), niger (Guizotia abyssinica (L. f.) Cass.), kodo (Paspalum scrobiculatum), kutki (Panicum sumatrance), mandwa (Eleusine coracana), sorghum (Sorghum bicolor), field pea (Pisum sativum), chickpea (Cicer arietinum), lentil (Lens esculenta), rai (Brassica juncea), linseed (Linum usitatissimum L.) etc in the Kharif and Rabi seasons.

Plant Protection:

Use of Ash:

Ash obtained from fuel wood or cow dung cake is broad-casted over the crop and at fruiting stage of various crops (eg. Mustard (Brassica nigra), dolichos bean (Lablab pur-pureus), cabbage (Brassica oleracea var. capitata; Brassica oleracea var.)) to protect from insects and diseases. It is a very common and very popular zero cost practice used by the majority of the farmers. Ash provides

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protections to plants against various insects like Red pumpkin beetle (Aulacophora foveicollis), flea beetle (Phyllotreta cruciferae), aphid (Lipaphis erysimi)

Storage:

Soil coating for preservation of seed. After the harvesting of crops (E.g. pigeon pea, chickpea, pea etc.), tribal farmers store the seeds for growing crops next year. The seeds are preserved by coating with soil. Coating is done by mixing soil and water to form a paste in a container and then seeds are transferred into that container mixed well, so that the soil paste completely covers the seeds. Soil paste coated seeds are dried properly under shade. Dried soil coated seeds are stored in a separate container or bag for next year. This traditional practice, although an effective strategy to protect against stored pests, is also diminishing at a faster rate.

Use of dry Neem leaves:

Use of Azadirachta indica (neem) in crop protection is very cost-effective and is in practice by the majority of the farmers. Green neem leaves are collected and dried properly under shade. These dried leaves are mixed with grains and filled in the bags or storage structures. Use of dry Vitex negundo (Nirgundi) leaves. Similarly to neem leaves, Nirgundi leaves are also used as a storage insecticide. Green leaves are collected and dried well under shade and mixed with grain and stored for a longer period. Nirgundi leaves reduce the infestation of various stored grain insects.

Hanging of maize (Zea mays) cobs:

Hanging of harvested dried cobs is a very common practice to keep maize cobs for future use. Mature harvested maize cobs are hung on the roof of the house preferably in smoke emitting areas such as the kitchen with the help of cobs leaves. Hanged cobs remain untouched with soil and are safe for a longer period from infestation by stored grain pests.

Storage structure:

Grains storage structure is used by farmers, locally called Kothi. The structure is made with the help of baked bricks and soil. The traditional storage structure is eco-friendly, less expensive, easy to apply, needs no formal training and grains can be stored for a longer period.

Agricultural practices such as ploughing of the fields with desi hal, bakhar, growing of traditional crops in kharif and Rabi seasons, mixed cropping, Winnowing using basket and wind, threshing manually and by bullock, manual pulling of weeds, harvesting by sickle, late sowing of niger, early sowing of rai, manual weeding, manual broadcasting of seeds and usage of neem leaves for storage of seeds were practiced in the fields.

Discussion:

Traditional knowledge on agricultural practices acquired by the indigenous communities has become the backbone of today's natural and sustainable farming. These traditional farming practices have been documented or some even have remained undocumented till date. However, they are in practice right from field preparation to harvesting to storage of seeds. Desi hal commonly known as Nagar is known to see the soil enough to create favorable conditions for seed placement and plant growth. It is a very effective implement for keeping the soil in good physical condition and is cost effective, easy to carry and a low maintenance implement. Interestingly, farming does not require technical knowhow during working with hal and can be used for ploughing, puddling and even sowing of crops, where tillage depth can be adjusted by applying manual force with palm. Another farming implement is Bakhar, this wooden implement has a soil cutting blade made up from iron. It is an implement for seed bed preparation and also serves as leveler when it is drawn in inverted position and is used to cover the broadcasted seed with soil.

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Conclusion:

Further taking in view the shift of Indian agriculture from traditional to modern to sustainable agriculture, which takes into account the limitations of production as well as socio-economic status of the farmers while using eco-friendly natural farming practices thus minimizing the effects on environment. In addition, the ever changing climate is posing a threat to the Indian scenario where a large population is based upon agriculture directly or indirectly. Thus, usage of these enriched technical traditional know-how since time immemorial can act as a boon to the Indian farming community to not only improve the quality and quantity of crop and live-stock production but also in terms of mitigating the dangers posed by climate change. Taking in view the same, a lot of work needs to be carried from local to regional to global level in documentation of this traditional technical knowledge, its scientific validation and dissemination of the same to various parts of the world according to the needs and landscape requirements

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Effect of Natural Farming on Cost of Production

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Introduction

Agriculture is an important source of livelihood and food security. The cost of cultivation has increased due to rising prices of chemical fertilizers, pesticides, seeds, irrigation, machinery and labour. These expenses can reduce the net income of farmers, particularly when crop prices are uncertain. Natural farming is an ecological approach that aims to reduce dependence on purchased external inputs and make greater use of locally available farm resources.

Natural farming generally avoids or minimizes synthetic fertilizers and pesticides and emphasizes biological processes, soil cover, recycling of farm residues, biodiversity and efficient use of water. Locally prepared inputs such as farm-based microbial formulations, botanical preparations and organic materials may be used according to the farming system. Because many inputs can be prepared on the farm, natural farming has the potential to reduce cash expenditure on purchased inputs.

However, reduction in production cost is not automatic. Labour for preparing inputs, mulching, intercultural operations and maintaining biodiversity may increase in some situations. Therefore, the effect of natural farming should be assessed by considering all major components of cost as well as yield, quality, market price and net returns.

2. Major Components of Cost of Production

The cost of production in agriculture includes both variable and fixed expenses. Variable costs include seed, fertilizers, plant protection materials, labour, irrigation, fuel and other operating expenses. Fixed costs include depreciation on farm machinery, land-related costs and interest on fixed capital. Natural farming mainly influences variable costs, particularly expenditure on fertilizers and chemical plant protection.

1. Seed cost: Natural farming may encourage farmers to use locally adapted seed, farm-saved seed or suitable varieties. This can reduce dependence on purchased seed in some crops, although certified seed may still be necessary for particular crops.

2. Nutrient management cost: Synthetic fertilizers can be a major purchased input. Natural farming emphasizes nutrient recycling through crop residues, animal-based resources, green manures, biomass and other locally available materials. This can reduce cash expenditure when these resources are available on the farm.

3. Plant protection cost: Natural farming promotes preventive crop protection through biodiversity, healthy soils, botanical preparations and biological methods. This may reduce expenditure on synthetic pesticides, although pest and disease management still requires regular monitoring.

4. Labour cost: Labour requirements may increase during preparation of farm-made inputs, mulching, weeding and other ecological practices. Mechanization and good farm planning can help manage this cost.

5. Irrigation and energy cost: Practices such as mulching, soil cover and improved soil moisture management can reduce water loss and may improve

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water-use efficiency. The actual saving depends on crop, soil, climate and irrigation method.

3. Effect on Different Production Costs

The most noticeable economic effect of natural farming can be a reduction in purchased external inputs. When farmers produce inputs using materials already available on the farm, the money spent on fertilizers and pesticides can decrease. This is particularly useful for small and marginal farmers who may have limited access to working capital.

Natural farming can also lower the cost of waste disposal because crop residues, animal wastes and other biomass can be recycled within the farm. Instead of treating these materials as waste, they can become resources for soil and crop management. This promotes nutrient cycling and can reduce the need to purchase some inputs.

At the same time, labour costs should be considered carefully. Weed management, mulching, preparation of farm inputs and manual crop monitoring may require additional labour, especially during the transition period. If family labour is available, the cash cost may remain low. If hired labour is required, the economic advantage may be smaller.

The cost of plant protection may decrease when preventive and biological approaches successfully control pests and diseases. However, natural farming does not mean that crops are free from pests. Regular observation and timely management are essential to avoid losses.

Soil management is another important aspect. Continuous use of ecological practices can support soil biological activity and improve the efficient use of available nutrients. The economic benefit from improved soil health may appear gradually rather than immediately in the first season.

4. Effect on Yield and Net Returns

Cost of production should not be evaluated separately from yield. A reduction in input expenditure is beneficial only when crop yield and farm income remain satisfactory. During the initial transition to natural farming, yields may vary depending on the crop, soil fertility, previous management, climate and farmer experience. Farmers therefore need to monitor both physical output and economic returns.

Net return is generally calculated by subtracting the total cost of cultivation from the gross return. Gross return depends on yield and the price received by the farmer. If natural farming reduces production costs while maintaining yield and obtaining a suitable market price, net returns can improve.

Quality and market opportunities may also influence profitability. Consumers may show interest in food produced using environmentally friendly methods, but farmers should not assume that a premium price will always be available. Local market demand, certification or verification requirements, transportation and marketing costs should be considered before making economic decisions.

5. Economic Advantages of Natural Farming

- Reduced expenditure on purchased synthetic fertilizers and pesticides.
- Better utilization and recycling of farm wastes and locally available resources.
- Lower dependence on external agricultural inputs.
- Potential improvement in soil health and resource-use efficiency over time.
- Reduced exposure to fluctuations in prices of some external inputs.
- Greater scope for using family labour and locally available materials.
- Possibility of improving net farm income when savings are greater than additional costs.

6. Limitations and Challenges

Natural farming also has challenges. Availability of biomass, animal resources and water can differ between farms. Preparing farm-made inputs requires knowledge, time and labour. Weed control may become difficult where adequate mulching or labour is not available. In some situations, crop yields may be affected during the transition period.

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Farmers also need reliable information, demonstrations and technical guidance. Market access is important if farmers expect better prices for produce. Economic results can differ widely between crops and regions, so natural farming should be evaluated under local conditions rather than assuming the same cost savings for every farm.

7. Measures to Improve Cost Efficiency

Farmers can improve the economic performance of natural farming by planning resource use carefully. Crop residues should be recycled wherever practical, and locally available biomass should be used efficiently. Crop rotation, mixed cropping and border or trap crops can support ecological pest management and diversify farm income.

Keeping farm records is essential. Farmers should record expenditure on labour, seed, irrigation, machinery and other inputs, along with yield and selling price. Comparing these records across seasons helps determine whether a particular practice actually reduces cost and improves returns.

Training and farmer-to-farmer learning can also reduce mistakes and improve the preparation and application of farm-based practices. Gradual adoption, demonstration plots and crop-specific planning can help farmers evaluate results before expanding a practice to the entire farm.

8. Conclusion

Natural farming can influence the cost of production by reducing dependence on purchased fertilizers, pesticides and other external inputs and by encouraging recycling of resources available on the farm. This can lower cash expenditure and potentially improve farm profitability. However, labour, management and transition costs must also be included in the economic assessment.

The overall effect depends on crop, location, resource availability, management skill, yield and market price. Therefore, natural farming should be evaluated using total cost, yield, gross return and net return rather than looking only at input savings. With suitable knowledge, careful planning and efficient use of local resources, natural farming can contribute to a more resource-efficient and economically sustainable farming system.

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Economic Viability of Natural Farming for Small Farmers

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Introduction

Natural farming is economically viable for small farmers because it cuts production costs by up to 60% to 70% through the elimination of expensive chemical fertilizers and pesticides but its short -term economic viability is challenged by a transition yield dip and higher labour requirement.

Smallholder farmers globally face a persistent economic squeeze: the escalating costs of synthetic fertilizers, chemical pesticides, and hybrid seeds frequently outpace the market prices they receive for their harvests. This high-input, high-debt cycle leaves many vulnerable to climate shocks and market volatility.

Natural farming—an agricultural approach that eliminates synthetic inputs entirely in favour of biological synergies, on-farm residues, and indigenous microbial preparations—has emerged as a compelling alternative. Beyond its well-documented ecological benefits, the most urgent conversation surrounding natural farming today focuses on its economic viability for small-scale and marginal farmers.

The most important economic advantages which enhances the economic viability of small farmers are :

❖ **Reduction in Cost of Cultivation :** One of the major economic advantages of natural farming is the possibility of reducing variable input costs.

Conventional farming may require:

- Chemical fertilizers
- Synthetic pesticides
- Herbicides
- Growth-promoting chemicals
- Purchased seed and other inputs
- Irrigation and machinery inputs

Natural farming attempts to replace or reduce several purchased inputs through:

- Farm-made biological inputs
- Crop residues
- Farmyard manure
- Animal-based resources
- Botanical preparations
- Mulching
- Biological pest management
- Economic effect

Lower input expenditure → lower total cost of cultivation → potentially higher net income.

❖ **Reduction in Dependence on Chemical Fertilizers**

Chemical fertilizers can represent a significant recurring expenditure

Natural farming emphasizes:

- Biological activity in soil
- Recycling of nutrients
- Use of locally available biomass
- Organic and biological inputs

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- Improved nutrient cycling

The farmer may therefore reduce dependence on purchased fertilizers.

Benefit to small farmers:

If fertilizer prices increase, a farmer who depends heavily on purchased fertilizers faces higher production costs. A farmer who can obtain a significant proportion of inputs from the farm may be less affects.

Use of Locally Available Resources

Natural farming encourages farmers to use resources already available on or around the farm.

Examples include:

- Crop residues
- Farmyard manure
- Livestock dung
- Livestock urine
- Green biomass
- Leaves
- Weeds where appropriate
- Farm wastes

Instead of purchasing every agricultural input, some resources can be recycled within the farming system.

Economic principle Farm waste → farm input → reduced external expenditure .This converts materials that might otherwise have little economic value into useful farm resource.

❖ **Role of Livestock in Economic Viability**

Livestock integration can strengthen the economics of natural farming.

Livestock can provide:

- Dung
- Urine
- Milk
- Manure
- Additional income
- Farm labour in some traditional systems
- Crop residues can also contribute to livestock feeding.

Thus:

Crop + livestock integration → resource recycling + additional income

A small farmer does not necessarily have to depend entirely on crop income.

Recycling of Nutrients

Nutrient recycling is important for maintaining the economic efficiency of a farm.

For example:

- Crop production → crop residues → livestock/feed/compost/mulch → soil → crop production

Similarly:

- Livestock → dung and urine → farm inputs → crop production
- This creates a circular farming system.

Economic advantage

The same resource can provide benefits to more than one farm enterprise, reducing wastage and improving resource-use efficiency.

❖ **Reduction in Pesticide Expenditure**

Natural farming emphasizes ecological approaches to pest management.

Methods may include: Botanical extracts ,Biological control, Habitat management, Crop diversification, Intercropping, Trap crops, Natural enemies, Preventive crop management.

These approaches can reduce expenditure on synthetic pesticides.

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Economic importance

Lower pesticide expenditure can:

Reduce the cost of production

Reduce dependence on external markets

Reduce the financial risk associated with repeated pesticide applications

However, farmers still need effective pest monitoring and management. Natural farming should not be interpreted as simply doing nothing about pests.

Case Study: Economics Of Natural Farming In Turmeric

A field experiment reported by the ICAR Research Complex for the North Eastern Hill Region, Umiam, Meghalaya, provides a useful example of the economic performance of natural farming. The study compared complete natural farming with a control treatment, an AI-NPOF package and integrated crop management in turmeric.

Under the complete natural farming treatment, the package included Beejamrit, Ghanjeevamrit and Jeevamrit, crop-residue mulching, intercropping and Whapasa. The reported cost of cultivation was ₹60,397/ha, turmeric yield was 11,600 kg/ha and net returns were ₹71,365/ha.

For comparison, the control treatment recorded a cost of cultivation of ₹53,468/ha, yield of 9,500 kg/ha and net returns of ₹65,231/ha. Thus, in this particular experiment, complete natural farming involved a higher cultivation cost than the control but produced higher turmeric yield and higher net returns.

The same ICAR report also shows that economic performance varied among natural-farming treatments and crops. The AI-NPOF package recorded the highest net return in the turmeric experiment, while natural farming produced higher mustard seed yield than the control in the reported trials. This indicates that the economic outcome of natural farming is context-specific and depends on the crop, package of practices and local conditions.

Economic significance: This case study supports the main argument of this article that natural farming should be evaluated using both costs and returns rather than by considering input reduction or yield alone. It also demonstrates why crop-specific economic analysis, including cost of cultivation, gross returns, net returns and B:C ratio, is important when assessing viability for small farmers.

Treatment	Cost (₹/ha)	Yield (kg/ha)	Net returns (₹/ha)
Control	53,468	9,500	65,231
Complete Natural Farming	60,397	11,600	71,365
AI-NPOF package	75,529	21,970	158,610

Source: ICAR, Indian Farming, August 2025, report on natural farming experiments at ICAR Research Complex for NEH, Umiam, Meghalaya.

Conclusion

Natural farming has considerable potential to be economically viable for small farmers because it can reduce dependence on purchased inputs, lower cultivation costs, recycle farm resources, diversify income sources and reduce production risks. Integration of crops and livestock, efficient resource utilization, direct marketing, value addition and collective marketing can further improve economic returns.

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However, economic viability is not automatic. It depends on local conditions, crop choice, labour availability, resource availability, transition-period performance, yield, market access and price realization. Therefore, natural farming should be evaluated using cost of cultivation, gross returns, net returns, B:C ratio, labour use and risk, rather than considering yield alone.

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Changing Weed Flora Under Climate Change

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Meaning of Weed Flora

Weed flora refers to all the weed species found in a particular agricultural field, region, or ecosystem.Weeds are unwanted plants that grow along with crops and compete for water, nutrients, sunlight, andspace.

Examples: Parthenium, Cyperus rotundus, Echinochloa, and Amaranthus species.

Meaning of Climate Change

Climate change refers to long-term changes in temperature, rainfall, weather patterns, and other climatic

conditions on Earth. Climate change affects agriculture, crop production, soil properties, and weed

growth. Changes in temperature and rainfall can alter the types, distribution, and abundance of weeds in

agricultural fields.

Changing Weed Flora

Changing weed flora means changes in the types, number, distribution, and dominance of weed species

due to environmental changes, especially climate change. Climate change can cause some weeds to

spread into new areas, while other weed species may decrease because of unsuitable environmental

conditions.

Importance of Studying Changing Weed Flora

- Helps to identify new and emerging weeds.
- Improves weed management practices.
- Reduces crop yield losses.
- Helps farmers adapt to changing climatic conditions.
- Supports sustainable agricultural production.

Factors Affecting Weed Flora Under Climate Change

Increase in Temperature

Rising temperatures influence weed seed germination, plant growth, flowering, and seed production.

- Warm conditions may increase the growth of heat-tolerant weeds.
- Some weeds can spread into cooler regions.
- Higher temperatures may allow certain weeds to produce more generations in a year.
- Temperature changes can alter the competitive ability of weeds and crops.

Changes in Rainfall

Rainfall affects soil moisture, weed germination, and plant survival.

- Increased rainfall may promote weed growth in suitable conditions.
- Reduced rainfall can favor drought-tolerant weeds.
- Irregular rainfall may change the timing of weed emergence.
- Heavy rainfall can transport weed seeds to new locations.

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Increased Carbon Dioxide (COl)

Carbon dioxide is an important gas used by plants during photosynthesis. Higher atmospheric COI

levels may increase the growth of some weed species.

- May increase biomass production in certain weeds.
- Can influence weed competition with crops.
- May affect herbicide response in some weed species.
- The effect varies according to weed species and environmental conditions.

Changes in Soil Moisture

Climate change can cause droughts, floods, and fluctuations in soil moisture. These changes influence

the germination and survival of weed seeds. Weeds that tolerate dry or waterlogged conditions may

become more common in certain areas.

Effects and Changes in Weed Flora

Change in Weed Distribution

Climate change can cause weeds to spread from one geographical region to another.

- Weeds may grow in new areas due to rising temperatures.
- Changes in rainfall influence weed distribution.
- Invasive weeds may spread rapidly under suitable climatic conditions.
- New weed species may appear in agricultural fields.

Change in Weed Dominance

Weed dominance refers to the weed species that are most abundant in a particular area. Climate

change can favor certain weed species over others. As a result, the dominant weed species in a field

may change over time.

Example: Drought-tolerant weeds may become more dominant during prolonged dry conditions.

Change in Weed Germination

Temperature and moisture affect the germination of weed seeds.

- Early or delayed weed emergence may occur.
- Weed emergence periods may change.
- Some weeds may germinate several times during the growing season.
- Changes in germination can affect crop–weed competition.

Change in Weed Growth and Reproduction

Climate change influences weed growth, flowering, and seed production. Some weeds may grow faster

under favorable conditions. Changes in the flowering period can also affect seed production and the

spread of weeds.

Invasive and New Weed Species

Climate change may support the establishment of invasive weed species in new environments. Invasive weeds can compete with crops and native plants, potentially reducing biodiversity and agricultural productivity.

Impact, Management, and Conclusion
Impact on Crop Production

Competition: Weeds compete with crops for essential resources.

Yield reduction: Heavy weed infestation can reduce crop yield.

Increased management cost: Farmers may need additional labor and weed control measures.

Herbicide effectiveness: Climate-related changes can influence weed growth and herbicide performance.

Pest and disease relationships: Some weeds may act as hosts for pests and plant pathogens

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Management of Changing Weed Flora

1. Integrated Weed Management (IWM)

Integrated Weed Management combines different weed control methods to manage weeds effectively and sustainably.

2. Cultural Methods

- Crop rotation.
- Timely sowing.
- Proper plant spacing.
- Use of competitive crop varieties.
- Maintaining good crop growth.

3. Mechanical Methods

- Hand weeding.
- Hoeing.
- Intercultivation.
- Removal of weeds before seed production

4. Chemical Methods

Herbicides can be used when appropriate. Selection and application should follow recommended agricultural practices, label instructions, and local guidance.

5. Biological Methods

Biological weed control uses natural enemies, such as selected insects or pathogens, to manage particular weed species.

6. Monitoring and Early Detection

Regular field monitoring helps identify newly emerging weeds and changes in weed populations.

Role of Farmers and Researchers

- Farmers should regularly monitor weed populations.
- Researchers should study climate effects on weed biology and distribution.
- Extension workers should provide updated weed management recommendations.
- Improved forecasting and early warning systems can help farmers prepare for changing weed problems.

Conclusion

Climate change is an important factor influencing weed flora in agricultural ecosystems. Changes in temperature, rainfall, atmospheric COI, and soil moisture can affect weed germination, growth, reproduction, distribution, and dominance.

Understanding changing weed flora helps farmers adopt suitable weed management practices, reduce crop losses, and improve sustainable agricultural production under changing climatic conditions.

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Status of Natural Farming Among Young Farmers

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1. Introduction

Natural farming is an ecological approach to agriculture that aims to reduce dependence on purchased synthetic inputs and make greater use of locally available farm resources. It emphasizes soil health, biodiversity, recycling of biomass, efficient use of water, and biological processes. The approach is closely associated with low-external-input agriculture and traditional knowledge, while also incorporating improved scientific understanding of soil and crop ecosystems.

Young farmers are important to the future of agriculture because they can combine farming experience with education, digital technologies, entrepreneurship, and new market opportunities. Their participation in natural farming can influence how quickly ecological practices are adopted and adapted to local conditions. However, adoption depends on knowledge, labour availability, access to training, market opportunities, farm size, risk perception, and the expected economic returns.

2. Subject of the Study

The subject of this assignment is the status of natural farming among young farmers. It focuses on their awareness, adoption of natural farming practices, sources of information, perceived benefits, constraints, and opportunities. The study also considers the role of agricultural education, extension services, farmer groups, digital media, and government programmes in encouraging young farmers to use ecological farming methods.

3. Objectives

- To understand the concept and major principles of natural farming.
- To examine the level of awareness of natural farming among young farmers.
- To identify commonly followed natural farming practices.
- To study the perceived economic, environmental, and social benefits.
- To identify major constraints affecting adoption.
- To suggest measures for improving participation of young farmers.

4. Concept and Principles of Natural Farming

Natural farming seeks to maintain the farm as a living ecosystem rather than treating crops only as isolated production units. Important principles include maintaining soil biological activity, protecting soil with organic residues or living cover, encouraging crop diversity, recycling farm wastes, and reducing unnecessary external inputs. Farmers may use locally prepared biological formulations, composts, mulches, botanical preparations, crop residues, livestock resources, and other farm-derived materials depending on the local system.

The central idea is to improve the efficiency and resilience of the farm ecosystem. Natural farming does not mean simply avoiding one category of input; successful practice requires appropriate crop selection, timely operations, water management, pest monitoring, nutrient management, and knowledge of local ecological conditions.

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5. Awareness Among Young Farmers

Awareness among young farmers is influenced by agricultural colleges, Krishi Vigyan Kendras, extension officers, farmer producer organizations, non-governmental organizations, farmer-to-farmer learning, social media, and practical demonstrations. Young farmers often have greater access to smartphones and online information, which can help them learn about alternative production methods. At the same time, online information may vary in quality, so scientific validation and field-based guidance are important.

Awareness should therefore include not only the definition of natural farming but also practical knowledge about preparation and use of farm resources, crop planning, soil management, pest and disease monitoring, record keeping, and safe handling of materials.

6. Adoption of Natural Farming Practices

Young farmers may adopt natural farming gradually rather than changing the entire farm at once. Common practices include use of farmyard manure and compost, mulching, recycling crop residues, crop rotation, mixed or intercropping, biological pest management, botanical extracts, and reduced use of synthetic inputs. The actual combination differs according to crop, climate, soil type, irrigation facilities, labour, and local knowledge.

Adoption can be assessed through the proportion of farmers using particular practices, the area under such practices, duration of adoption, frequency of application, and the extent to which external inputs have been reduced. Keeping farm records helps farmers compare production costs, yields, soil observations, and returns over several seasons

.7. Sources of Information and Extension Support

Extension support can strongly influence the confidence of young farmers. Demonstrations, training programmes, field schools, farmer meetings, and practical exposure allow farmers to observe the performance of natural farming practices under local conditions. Agricultural institutions can also support farmers by providing soil testing, crop advisories, pest identification, and guidance on farm-level experimentation.

Digital platforms can supplement, but not replace, field extension. Short videos, mobile advisories, online farmer communities, and digital marketplaces can improve access to information and customers. Young farmers can also become knowledge intermediaries by sharing successful practices with neighbouring farmers.

8. Benefits Perceived by Young Farmers

Natural farming may offer several potential benefits. Recycling farm resources can reduce expenditure on selected external inputs. Increased organic matter and biological activity can support soil quality when managed appropriately. Crop diversification can spread production risk and improve biodiversity. Reduced dependence on purchased inputs may also improve resilience to changes in input prices.

Environmental benefits may include improved nutrient cycling, reduced pollution risks from inappropriate input use, better soil cover, and conservation of beneficial organisms. The magnitude of these benefits varies with management practices and local conditions; therefore, claims about yield or profitability should be evaluated using farm records and multi-season evidence.

9. Economic Aspects

Economic performance is a major factor in adoption decisions. Young farmers generally consider input costs, labour requirements, yield, market price, product demand, certification or verification costs where applicable, and the time required to establish the system. Natural farming can lower some purchased-input costs, but preparation of farm-based inputs and manual weed or pest management may require additional labour.

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Market access is especially important. If consumers recognize and value products produced through ecological methods, farmers may have opportunities for differentiated marketing. However, such opportunities depend on local demand, reliable quality, transparent claims, aggregation, transport, and access to suitable markets.

10. Major Constraints

Several constraints may slow adoption among young farmers. These include lack of practical knowledge, uncertainty about yields during the transition period, insufficient labour, limited access to quality organic resources, difficulty in controlling weeds or pests, inadequate extension support, and limited market incentives. Farmers may also hesitate when information is inconsistent or when demonstrations are not available under their local conditions.

Another challenge is that young farmers may have limited control over family farming decisions, especially where land, finance, and machinery are managed jointly. Training programmes should therefore involve both young farmers and other household decision-makers.

11. Role of Government and Agricultural Institutions

Government departments and agricultural institutions can encourage natural farming through training, demonstrations, research, soil-health programmes, farmer groups, access to advisory services, and support for local resource-based enterprises. Agricultural universities and research institutions can contribute evidence on soil properties, crop productivity, pest management, economics, and long-term sustainability.

Support is most useful when programmes are adapted to local agro-climatic conditions and provide continuous guidance rather than one-time awareness campaigns. Monitoring adoption and documenting farm-level outcomes can help improve future programmes.

12. Opportunities for Young Farmers

Young farmers can connect natural farming with entrepreneurship by producing farm inputs from locally available resources, developing diversified farms, processing agricultural products, participating in farmer producer organizations, and using digital tools for marketing. Diversification with suitable crops, livestock, trees, and allied activities can strengthen resource recycling and create additional income opportunities.

Young farmers with agricultural education can also contribute to community learning by maintaining demonstration plots, documenting results, and helping neighbouring farmers understand both the advantages and limitations of natural farming.

13. Suggestions

• Provide practical, crop-specific training rather than only theoretical lectures.

• Establish demonstration farms where young farmers can observe practices across seasons.

• Strengthen extension support and access to reliable scientific information.

• Encourage farm record keeping to compare costs, yields, soil indicators, and returns.

• Promote farmer groups and collective marketing where appropriate.

• Support local production and recycling of farm-based inputs.

• Conduct long-term research on productivity, soil health, profitability, and resilience

14.. Challenges faced by young farmers

- Despite the opportunities, young farmers face several difficulties in adopting natural farming.
- One major challenge is the lack of adequate technical knowledge.

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- Natural farming requires proper understanding of soil, crops, pests, beneficial organisms and locally suitable practices.
- Another challenge is market access. Farmers need reliable buyers and suitable marketing channels to obtain better returns from their produce.
- Lack of certification, branding and organized marketing can also create difficulties.
- Young farmers may also be concerned about the transition period and possible changes in crop productivity.
- Availability of livestock-based resources and suitable local inputs can differ between farming households.
- Limited access to credit, training, extension services and demonstrations may further slow adoption.
- Therefore, practical support is important for encouraging wider participation.

15. Measures to promote Natural farming among young farmers

- The following measures can help increase adoption:
- Conduct regular training and practical demonstrations.
- Provide scientific and locally suitable technical guidance.
- Establish demonstration plots in villages and educational institutions.
- Improve access to reliable markets and value-addition facilities.
- Encourage farmer producer organizations and youth farming groups.
- Promote digital agricultural advisory services.
- Support young farmers through suitable schemes and institutional assistance.
- Encourage research on the economic and environmental performance of natural farming.
- Document and share successful farmer experiences.
- Provide opportunities for agricultural students and rural youth to gain practical experience.

16. Conclusion

- Natural farming presents an opportunity for young farmers to combine ecological resource management with modern agricultural knowledge and entrepreneurship.
- Its status among young farmers is shaped by awareness, practical experience, economic considerations, access to markets, labour, extension support, and confidence in the results.
- Greater participation is likely to depend on locally relevant demonstrations, reliable information, supportive institutions, and careful evaluation of farm-level outcomes.

Young farmers can play an important role in developing resilient agricultural systems when they are given opportunities to experiment responsibly, record results, learn from evidence, and adapt practices to their own soil, climate, crops, and available resources.

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Impact of Natural Farming on Farm Income

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1. Introduction

Natural farming is an ecological approach to agriculture that aims to reduce dependence on purchased external inputs and make greater use of locally available farm resources. It emphasizes soil cover, biological activity, crop diversity, recycling of biomass, natural pest-management methods and efficient use of water. In India, natural farming is commonly associated with practices such as Beejamrit, Jivamrit, mulching (Acchadana), Whapasa and botanical or biological plant protection. ICAR describes natural farming as an approach that uses environment-friendly inputs and practices to improve soil health, agro-biodiversity and self-sustaining production systems.

2. Meaning of Farm Income

Farm income is the economic return obtained from agricultural and allied farm activities after accounting for relevant production expenses. For a farmer, the important measure is not only gross income but also net income. Therefore, a farming practice can improve profitability either by increasing output and sale value, reducing the cost of cultivation, or both.

3. Why Natural Farming Matters for Income

Natural farming can influence income through several pathways. Reduced purchase of synthetic fertilizers and pesticides may lower cash expenditure. Recycling crop residues and livestock resources can reduce dependence on outside inputs. Crop diversification can provide several sources of revenue and reduce the risk associated with failure of one crop. Better soil condition and water conservation may also support more stable production over time.

4. Objectives of the Assignment

- To explain the concept and major practices of natural farming.
- To examine how natural farming can influence farm costs, returns and net income.
- To identify major economic benefits and limitations of natural farming.
- To suggest measures for improving the profitability of natural farming.

5. Major Natural Farming Practices and Their Economic Role

6. Reduction in Cost of Cultivation

One of the strongest economic arguments for natural farming is the possibility of reducing cash expenditure on external inputs. When farmers prepare inputs from locally available biomass, livestock resources and plant materials, expenditure

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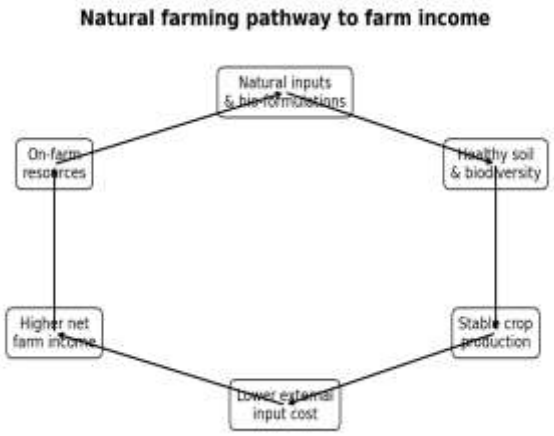
on certain commercial inputs can fall. However, labour, training, transport, livestock maintenance and preparation of farm inputs still have economic value and should be included when calculating profitability.

7. Evidence from Indian Experience

ICAR's compilation of state-specific strategies for doubling farmers' income reports a case from Krishna district in which a farmer shifted from chemical-intensive agriculture to Zero Budget Natural Farming. The report notes a relatively small yield decline in rice after adoption, while the farmer also obtained a bonus price for the grain. This illustrates that profitability depends on both production cost and the price received, not yield alone.

8. Impact of Natural Farming on Farm Income



8.1 Lower Input Expenditure

Natural farming seeks to reduce dependence on purchased fertilizers, pesticides and other external inputs. If farmers can meet a larger share of nutrient and plant-protection needs using resources available on the farm or locally, the cash cost of cultivation may decrease. A lower cost with similar output can directly increase net income.

8.2 Diversification and Additional Income

Natural farming is often practiced together with crop diversity, trees, livestock and recycling of farm resources. Diversification can provide income at different times of the year and reduce the financial impact of a single crop failure. ICAR examples of integrated farming systems show that combining crops with livestock and allied enterprises can substantially improve profitability and income stability.

8.3 Soil Health and Long-Term Productivity

Regular soil cover, biomass recycling and reduced chemical dependence can support soil biological activity and conservation of soil moisture. Better soil condition may lower some long-term production risks. Natural farming therefore has a potential income effect that is not limited to one season; however, the actual benefit depends on climate, soil, crop, management skill and local resource availability.

8.4 Better Market Value

Consumers may value produce associated with safer or environmentally friendly production. Where reliable markets, traceability, certification or farmer-group marketing exist, producers may obtain better prices. A higher price can compensate for lower or similar yield, but a premium should never be assumed without evidence from the local market.

8.5 Risk Reduction

Mixed cropping, crop diversification and integrated farm enterprises can spread production risk. This can make farm income more stable, especially in areas affected by drought, pest outbreaks or price fluctuations. ICAR reports that diversified integrated systems can reduce crop-loss risk compared with monocropping.

9. Challenges Affecting Income from Natural Farming

Transition period

During the initial years, farmers may need training, additional labour and changes in farm management. Yields may vary during the transition, so profitability should be assessed over several seasons.

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Labour requirement

Preparation of farm-made inputs, mulching, residue management, mixed cropping and manual weed management can require additional labour. The value of family labour should be included in economic calculations.

Marketing

A higher selling price is possible only when consumers, institutions or organized markets recognize the product's quality. Weak market linkages can reduce the expected income advantage.

Knowledge and skill

Natural farming is management-intensive. Incorrect preparation or inappropriate application of inputs can reduce effectiveness. Training and field demonstrations are therefore important.

Location-specific performance

Results are not identical in every crop, soil and climate. Natural farming should be evaluated using local yield, cost, labour and market data rather than assuming a fixed income increase.

10. Measures to Improve Farm Income through Natural Farming

- Provide farmer training, demonstrations and scientific advisory support.
- Promote crop diversification, intercropping and suitable integrated farming systems.
- Develop farmer groups, local processing and direct marketing channels.
- Maintain farm records of input cost, labour, yield, selling price and net returns.
- Use locally available biomass and livestock resources efficiently without compromising animal welfare or soil fertility.
- Encourage research and location-specific recommendations based on multi-season field trials.

11. Conclusion

Natural farming can improve farm income mainly by reducing dependence on purchased inputs, encouraging diversification, recycling farm resources and potentially improving the stability of production. Its economic success should be judged by net returns rather than yield alone. Evidence from Indian farming-system experiences shows that low-cost resource recycling and diversification can strengthen profitability and livelihood security, but outcomes vary among farms. Therefore, natural farming should be promoted with proper training, local experimentation, reliable markets and careful farm-level cost-benefit analysis.

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Micro Irrigation for Water Saving Agriculture

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1. Introduction

Water is one of the most critical and increasingly scarce inputs in modern agriculture. With the growing global population, expanding urbanisation, and the intensifying effects of climate change, the availability of fresh water for irrigation is under severe pressure. Agriculture currently consumes nearly 70 percent of the world's freshwater withdrawals, yet a large share of this water is lost through evaporation, runoff, and deep percolation under conventional flood or furrow irrigation methods. In this context, micro irrigation has emerged as one of the most effective agronomic innovations for conserving water while simultaneously improving crop productivity and quality.

Micro irrigation, also known as localized irrigation, is a modern method of applying water in small, precise, and frequent quantities directly to the root zone of the plant through a network of pipes, valves, and emitters. Unlike traditional irrigation systems that wet the entire field surface, micro irrigation targets only the area where the plant roots are active, thereby minimizing losses and maximizing the efficiency of water use. This document presents a comprehensive overview of micro irrigation as a water-saving strategy in agronomy, covering its concept, types, components, advantages, limitations, and its role in sustainable crop production.

2. Need for Water-Saving Agriculture

Freshwater resources are finite, and the per capita availability of water is declining steadily across the world due to population growth, industrial demand, and depletion of groundwater tables. Several regions already experience acute water stress during critical crop growth stages. Conventional irrigation methods such as flood and furrow irrigation are highly inefficient, with water use efficiency often as low as 30 to 40 percent, since a substantial portion of the applied water is lost to evaporation, deep percolation beyond the root zone, and surface runoff.

The need for water-saving agriculture arises from several interconnected factors:

- Rapid depletion of groundwater tables in intensively irrigated regions
- Erratic and reduced rainfall patterns caused by climate change
- Increasing competition for water between agricultural, domestic, and industrial sectors
- Rising energy costs associated with pumping and lifting water
- The necessity of achieving higher crop yields from limited cultivable and water resources

Micro irrigation directly addresses these challenges by drastically reducing the quantity of water required per unit of crop produced, making it a cornerstone technology for climate-resilient and sustainable agronomy.

3. Concept of Micro Irrigation

Micro irrigation is defined as the frequent and slow application of water directly to the soil surface or root zone of the crop through a low-pressure network of pipes and emission devices. The system operates at low discharge rates, typically between 2 and 20 litres

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per hour per emitter, and maintains soil moisture at near-optimal levels throughout the crop growth period. Because water is applied precisely where it is needed, both in space and time, wastage through evaporation and deep percolation is minimized.

The fundamental principle behind micro irrigation is to maintain the soil moisture in the active root zone close to field capacity, thereby avoiding both water stress and waterlogging. This precise control not only conserves water but also creates favourable soil aeration and nutrient availability conditions, resulting in improved plant growth, uniform crop stands, and higher quality produce.

4. Types of Micro Irrigation Systems

4.1 Drip Irrigation

Drip irrigation, also called trickle irrigation, applies water drop by drop directly at the base of each plant through emitters or drippers fixed on lateral pipes. It is the most widely adopted micro irrigation method and is highly suitable for row crops, orchards, vegetables, and plantation crops such as sugarcane, cotton, grapes, and banana.

4.2 Micro-Sprinkler / Mini-Sprinkler Irrigation

Micro-sprinklers distribute water in a small circular or fan-shaped spray pattern over a limited area around the plant. This method is well suited to crops with shallow root systems, closely spaced plantations, and orchards, and it also assists in providing localized frost protection and canopy cooling.

4.3 Bubbler Irrigation

In bubbler irrigation, water is discharged at a small but higher flow rate than drip emitters, creating a small basin or pond around the plant base. It is commonly used for widely spaced trees and orchard crops with higher individual water requirements.

4.4 Sub-Surface Drip Irrigation (SDI)

Sub-surface drip irrigation involves burying the lateral lines with emitters below the soil surface, delivering water directly into the root zone. This method further reduces evaporation losses, suppresses weed growth on the soil surface, and is particularly effective for field crops and long-duration plantations.

Comparison of Irrigation Methods

Feature	surface irrigation	sprinkler irrigation	drip(micro) irrigation
4.5 Water Use Efficiency	30–40%	60–70%	85–95%
Water Loss	Very High	Moderate	Very Low
Suitability	Flat, heavy soils	Most crops & soils	Row crops, orchards, vegetables
Labour Requirement	High	Moderate	Low (after setup)
Weed Growth	High	Moderate	Low
Initial Cost	Low	Moderate	High
Fertilizer Application	Difficult	Possible	Highly Efficient (Fertigation)

5. Components of a Micro Irrigation System

A typical micro irrigation system consists of several interconnected components that work together to deliver water and nutrients efficiently to the crop root zone. The major components are summarised below.

components	Function
Water Source	Well, borewell, tank, canal or reservoir supplying water to the system

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Pump Unit	Draws water from the source and delivers it under pressure into the pipe network
Filtration Unit	Sand filter, screen filter and hydrocyclone filter remove suspended solids to prevent emitter clogging
Fertigation Unit	Venturi injector or fertilizer tank that mixes soluble fertilizers with irrigation water
Control Valves	Regulate flow and pressure at the head of the system and at sub-units
Main and Sub-main Pipes	PVC/HDPE pipes that carry water from the head unit to the field
Lateral Pipes	Smaller pipes laid along crop rows that carry water to the emitters/drippers
Emitters / Drippers / Nozzles	Deliver water in drops (drip) or fine spray (micro-sprinkler) directly to the root zone

6. Advantages of Micro Irrigation

6.1 Water Conservation

Micro irrigation can achieve water use efficiencies of 85 to 95 percent, compared to 30 to 40 percent under surface irrigation, resulting in water savings of 40 to 70 percent depending on the crop and soil type.

6.2 Enhanced Crop Yield and Quality

By maintaining optimum soil moisture and enabling precise fertigation, micro irrigation improves nutrient uptake efficiency, leading to higher yields, better fruit size and quality, and more uniform crop maturity.

6.3 Fertilizer Use Efficiency (Fertigation).

Soluble fertilizers can be injected directly into the irrigation water and delivered precisely to the root zone, improving nutrient use efficiency by 20 to 30 percent while reducing fertilizer wastage and leaching losses.

6.4 Weed and Disease Control

Since only the root zone is wetted and the inter-row spaces remain dry, weed germination is significantly reduced. Lower humidity around the foliage also minimizes the incidence of fungal and bacterial diseases.

6.5 Labour and Energy Savings

Automation of micro irrigation systems through timers and controllers reduces the labour required for irrigation management and lowers energy consumption due to the low operating pressure of the system.

6.6 Suitability for Problem Soils and Terrains

Micro irrigation can be effectively used on undulating land, sandy soils with high infiltration rates, and saline soils, where conventional flood irrigation is inefficient or impractical.

7. Limitations and Challenges

- High initial investment cost for equipment, installation, and infrastructure
- Risk of emitter clogging due to suspended solids, algae, or chemical precipitates in irrigation water
- Requirement of technical knowledge for system design, operation, and maintenance
- Limited suitability for closely spaced field crops such as paddy grown under submerged conditions
- Damage to pipes and laterals from rodents, sunlight (UV degradation), and farm operations
- Need for a regular and reliable power supply to operate the pumping unit

Despite these challenges, proper system design, adequate filtration, regular maintenance, and farmer training can substantially mitigate these limitations, making micro irrigation a viable long-term investment.

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8. Government Support and Promotion

Recognising the critical importance of water-use efficiency in agriculture, many countries have introduced dedicated schemes and subsidies to promote micro irrigation adoption among farmers. In India, for example, the Per Drop More Crop component under the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) provides financial assistance covering a significant percentage of the cost of drip and sprinkler irrigation systems, along with support for micro irrigation fund schemes implemented through state agricultural and horticulture departments. Such policy interventions aim to accelerate the shift from conventional to efficient irrigation methods, particularly in water-stressed and drought-prone regions.

9. Illustrative Impact on Crop Water Productivity

Field studies across various crops have consistently demonstrated the water-saving potential of micro irrigation. In sugarcane, drip irrigation has been reported to save 30 to 60 percent of irrigation water compared to furrow irrigation while increasing yield by 20 to 30 percent. In cotton, water savings of 40 to 50 percent along with yield increases of 25 to 30 percent have been recorded. Similarly, vegetable crops such as tomato and capsicum grown under drip irrigation with plastic mulch show water savings exceeding 50 percent along with substantial improvements in fruit quality and shelf life. These outcomes underline the dual benefit of micro irrigation: conserving a scarce natural resource while enhancing farm productivity and profitability.

10. Operation and Maintenance Practices

The long-term success and water-saving efficiency of a micro irrigation system depend heavily on proper operation and regular maintenance. Neglecting routine upkeep is one of the most common reasons for system failure and farmer dissatisfaction with the technology. The following practices are recommended for sustaining system performance:

- Regular cleaning or backwashing of sand, screen, and hydrocyclone filters to prevent clogging of emitters
- Periodic flushing of main, sub-main, and lateral lines to remove accumulated sediment
- Chemical treatment (chlorination or acid treatment) to control algal growth and dissolve chemical precipitates inside pipelines
- Routine inspection of emitters and drippers for uniform discharge and timely replacement of damaged parts
- Protection of above-ground laterals from rodents, farm implements, and prolonged direct sunlight
- Monitoring of operating pressure at the pump and at the field level using pressure gauges

Extension agencies and agricultural universities play an important role in training farmers on these operation and maintenance practices, ensuring that the water-saving benefits of micro irrigation are realised consistently over the useful life of the system, which typically ranges from 7 to 15 years depending on component quality and water quality.

11. Future Prospects

The future of micro irrigation lies in its integration with emerging digital and precision agriculture technologies. Soil moisture sensors, automated weather stations, and Internet of Things (IoT)-based controllers are increasingly being coupled with drip and micro-sprinkler systems to schedule irrigation based on real-time crop water demand rather than fixed time intervals. Solar-powered pumping units are also being combined with micro irrigation to reduce dependence on grid electricity and diesel, lowering both operating costs and the carbon footprint of irrigated agriculture.

Further research is focused on developing low-cost, indigenous drip components suited to smallholder

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farms, improving emitter designs that resist clogging under poor water quality, and integrating micro irrigation with protected cultivation structures such as greenhouses and polyhouses. As these innovations mature and become more affordable, micro irrigation is expected to expand beyond high-value horticultural crops into staple field crops, further amplifying its contribution to national and global water security.

12. Crop Suitability for Micro Irrigation

Not all crops derive equal benefit from micro irrigation, and appropriate crop selection is important for maximizing the return on investment. Micro irrigation is best suited to high-value, wide-spaced, and long-duration crops where the cost of installation can be recovered through improved yield and quality.

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Innovations in Bio-stimulants and Fertilizer Technologies

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Introduction

Feeding a crop used to be a fairly simple exercise: test the soil, compare the numbers with a recommendation and apply enough fertilizer to close the gap. Biosciences argued that this approach, while still a useful foundation, no longer tells the whole story. (Matthews *et al* 2025). Growers today are expected to raise yields, use inputs efficiently and limit losses to the environment, all at the same time. It was organised around four ideas: a comparison of traditional and newer fertilization approaches; the established fertilizer technologies, namely slow and controlled release fertilizers and fertilizer stabilizers; the newer plant growth technologies, including bio stimulants such as microbials; and finally, the role of research and applications in driving fertilizer and bio stimulant innovation. This article follows that same path (Miranda *et al* 2024).

The Traditional Approach: Start with the Soil

The talk began with what it called the **traditional fertilization approach for beginners**. It has two steps: run a soil test, then apply enough fertilizer to meet the soil test recommendations. This is known as the sufficiency approach, and its aim is to correct deficiencies.

Nutrient	**recommended level**
Sulfur	20 to 80 ppm
Zinc	1.8 to 3.5 ppm or a 10:1 P:Zn ratio
Manganese	20 to 40 ppm
Iron	20 to 40 ppm and always keep levels above manganese
Copper	1.4 to 2.0 ppm
Boron	1.2 to 3.0 ppm

Table 1. Sulfur and micronutrient based on Mehlich-3 extraction methods and the DTPA test

Stepping Up: Tissue Tests and Growth-Stage Uptake

For growers at the intermediate level, the focus shifts from the soil to the plant itself. The steps are to run a tissue test, look at nutrient uptake levels by crop growth stage, and apply enough fertilizer to meet the plant's needs at different growth stages. The goal is still to correct deficiencies, but the timing of supply now matters as much as the total amount.

Two charts supported this idea. The first, from the Purdue University soybean station (West Lafayette, Indiana, 2011-12), compared nitrogen accumulation in Maturity Group 2 soybeans from the 1960s with those of the 2010s. The second, from Iowa State University Extension, showed how a corn crop's nitrogen uptake builds across the vegetative and reproductive stages and how it is divided among the stalk and leaf sheaths, leaf blades, tassel, shanks, husks and cob, and grain, on a scale reaching 200 lb N per acre. Together they make the point that nutrient

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demand follows the crop's development rather than arriving all at once. (Matthews *et al* 2025).

Where the Traditional Approaches Fall Short

The presentation was frank about the limitations of both approaches. Field trial evidence suggests that adding fertilizer on the basis of soil test recommendations does not always pay off, as the figures below show.

Figure	What it shows
1/3 of 240 trials	Responded to broadcast phosphorus (data from Iowa State University)
Less than 1/4 of 2,100 trials	Responded to broadcast potassium (data from the University of Illinois)
Up to 27% more zinc	Removed by today's hybrids compared with non-rootworm resistant hybrids (Below, 2008)

Table 2. Evidence presented on the limitations of traditional fertilization. A companion chart showed a significant yield response in about 33% of trials for broadcast P_2O_5 and 24% for broadcast K_2O.

The zinc example is especially telling. Because modern hybrids remove more zinc, some soil test recommendations that were built around older assumptions do not account for the crop's real demand.

So, what is missing from traditional fertilization approaches? The answer was framed around the familiar principle of using the right source, rate, time and place:

- **Right Source:** not all fertilizers are equal.
- **Right Rate:** high rates of fertilizer can actually decrease yields.
- **Right Time:** plants do not take up all of the fertilizer at once.
- **Right Place:** fertilizer can be lost from the field into the environment.

An accompanying yield-response curve divided fertilizer additions into three zones: increased yield at low rates, a plateau beyond the optimum where extra fertilizer produces waste and pollution, and decreased yield at very high rates. (Matthews *et al* 2025)

Why New Fertilizer Technologies Matter

The two strong reasons for agriculture to adopt new fertilizer technologies. The first is environmental. The widespread blue-green algal bloom, attributed to phosphorus runoff from unincorporated fertilizer and manure combined with heavy rainfall. It is a vivid reminder of what happens when nutrients leave the field.

The second reason is **the yield gap**. The yield of top-performing growers (the yield winners) with the national average. For US corn the gap was about 366 bushels per acre and for US soybean about 87 bushels per acre. The contributors to this gap were listed as climate and weather, genetics, fertility, soil health and pests. The right specialty plant nutrition program can partially mitigate several of these contributors, and that the right plant nutrition tools make cropping practices effective, efficient and sustainable.

A Technological Revolution in Plant Nutrition

The conventional nitrogen, phosphorus and potassium (N, P and K) products as old technologies that come with inefficiencies, and it prompted the audience to think about how much farmers spend on fertilizer each year. The proposed direction is to apply plant-available fertilizer and to use bio stimulants so that nutrition matches the plant's growth cycles and the stresses that lie ahead. (Khoulati *et al* 2025).

A plant hormone cycle, it divides the crop's life into four stages: germination and establishment, vegetative growth, flowering and reproduction and maturity and senescence. Each stage is dominated by

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different hormones and each depends on its own set of nutrient co-factors. Any imbalance in the hormones and bio-available co-factors at any time can irreversibly limit yield, and that a customized approach is therefore required.

Established Tools: Enhanced Efficiency Fertilizers

Before turning to bio stimulants, the existing fertilizer efficiency technologies, typically called enhanced efficiency fertilizers. They fall into three groups:

- Slow and controlled release fertilizers
- Nitrogen stabilizers
- Phosphate management products

Nitrogen stabilizers received the closest look. They include **urease inhibitors** and **nitrification inhibitors** for examples listed were NBPT, DCD and nitrapyrin and well-known commercial products such as Agrotain, Agrotain Plus and NutriSphere-N were shown alongside.

The nitrogen cycle explains why these products are useful. Nitrogen in the field moves between organic N, ammonium (NH_4^+) and nitrate (NO_3^-), and can be lost through ammonia volatilization, denitrification, leaching and runoff and erosion, in addition to being taken up by the plant or immobilized. Urease inhibitors and nitrification inhibitors are positioned where losses begin, which is how stabilizers help keep nitrogen available to the crop (Rajesaheb *et al* 2025).

Newer Tools: Bio stimulants

The newer tools were introduced; **Bio stimulants** are active ingredients that improve crop yield and quality by enhancing four things:

- Stress tolerance and recovery
- Water-use efficiency
- Nutrient use efficiency
- Plant growth directly

A bio stimulant application reducing drought stress in wheat. A plant listed the kinds of stress involved: chemicals, drought, poor oxygen levels, temperature variation, light variation, high salt content and waterlogging. It places bio stimulants and biopesticides together under the broader heading of biologicals. Each of the two is further split into microbial and non-living types and the non-living bio stimulants are subdivided into hormones, extracts and synthetics. The bio stimulant groups covered in the talk as amino acids, humic and fulvic acids, seaweed extracts and microbials (Jmaili *et al* 2025).

Conclusion:

The soil and tissue tests should be abandoned, but that they are only the starting point. Traditional sufficiency-based fertilization corrects deficiencies, yet it does not by itself guarantee the right source, rate, time and place. Enhanced efficiency fertilizers, including nitrogen stabilizers, help protect the nutrients that are applied, while bio stimulants aim to help the crop cope with stress and make better use of water and nutrients. Used together and matched to the crop's growth stages, these tools form a more customized, efficient and sustainable approach to plant nutrition.

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Impact of Interior Design on the Quality of Life in Agricultural Households

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A home is much more than a structure made of walls, doors, and windows. It is the place where people spend a major part of their lives, perform daily activities, rest, interact with family members, and create memories. The way a home is planned and arranged can greatly influence the comfort, health, happiness, and efficiency of the people living in it. This is particularly important in agricultural households, where the home often serves several purposes beyond simply providing shelter.

Agricultural households have a unique lifestyle. Family members may spend their days working in fields, taking care of livestock, processing agricultural products, preparing food, and managing household responsibilities. In many cases, the same house may be used for cooking, storage, food processing, resting, studying, socializing, and sometimes even small-scale income-generating activities. Therefore, appropriate interior design can play an important role in improving the quality of life of agricultural families.

Interior design does not necessarily mean expensive furniture, decorative walls, or luxurious rooms. For agricultural households, it is more about using available space wisely and creating an environment that is comfortable, functional, safe, healthy, and suitable for the family's lifestyle.

Making Better Use of Available Space

One of the major benefits of good interior design is effective space utilization. Agricultural families may have to accommodate many household and farming-related items, including utensils, grains, seeds, clothes, agricultural tools, food products, and seasonal materials. When these items are not organized properly, the house can become crowded and difficult to move around in.

Simple solutions such as wall-mounted shelves, built-in storage, multipurpose furniture, under-bed storage, and designated storage areas can make a significant difference. Separating agricultural materials from everyday household items can also make the home cleaner and more organized.

Good space planning allows different activities to take place without disturbing one another. For example, cooking, sleeping, studying, and storage areas can be arranged in a way that provides greater convenience and privacy.

Improving Comfort and Reducing Physical Strain

Agricultural work can be physically demanding. After spending several hours working in the field or performing household tasks, family members need a comfortable environment for rest and recovery.

Interior design can help reduce physical strain through ergonomic furniture and appropriate workspaces. Kitchen platforms, tables, chairs, shelves, and storage units should be placed at comfortable heights. Frequently used objects should be kept within easy reach so that unnecessary bending, stretching, or lifting can be avoided.

This is especially important for women, who may perform both agricultural and household responsibilities. A properly planned kitchen with adequate storage, ventilation, lighting, and suitable

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working height can make everyday activities easier and less tiring.

Importance of Natural Light and Ventilation

Light and air are essential elements of a healthy home. Agricultural households may spend considerable time indoors for cooking, food processing, storage, and household activities. Poorly ventilated and dark interiors can make a house uncomfortable and may contribute to problems related to heat, moisture, smoke, and unpleasant odours.

Natural ventilation through windows, ventilators, courtyards, and properly positioned openings can improve air circulation. Good daylight can make rooms appear more spacious and pleasant while reducing dependence on artificial lighting during the day.

A well-ventilated kitchen is particularly important because cooking can generate heat, smoke, and moisture. Appropriate ventilation can make cooking more comfortable and contribute to a healthier indoor environment.

Creating a Safer Home

Safety is another important aspect of interior design. Agricultural households may contain farming tools, equipment, fertilizers, pesticides, fuels, and other materials that can be dangerous if stored carelessly.

These materials should be kept separately from food, cooking areas, and children's living spaces. Heavy objects should be stored securely, electrical connections should be properly maintained, and floors should preferably be non-slippery.

Furniture should not obstruct pathways, and sufficient space should be provided for movement. Adequate lighting in stairways, entrances, kitchens, bathrooms, and work areas can also help prevent accidents.

For older family members, safety becomes even more important. Proper seating, adequate lighting, accessible storage, and non-slip flooring can help them move around the home more confidently.

Supporting Mental and Emotional Well-being

The home environment can influence how people feel. A dark, overcrowded, noisy, or disorganized home may create feelings of discomfort and stress. On the other hand, a clean, organized, bright, and pleasant interior can create a sense of peace and satisfaction.

Agricultural households can incorporate natural elements into interiors through indoor plants, natural materials, traditional textiles, locally made handicrafts, and photographs. Such elements can make the home more attractive while maintaining a connection with local culture and rural life.

Colours can also influence the atmosphere of a room. Soft and natural colours can create a calm environment, while brighter colours can add energy to spaces such as kitchens or children's study areas.

Improving Family Interaction and Privacy

In many agricultural households, several generations may live together. While joint living can strengthen family relationships, it can sometimes create a lack of privacy.

Thoughtful interior planning can provide both shared and private spaces. A common living area can encourage family interaction, while partitions, curtains, screens, or separate sleeping arrangements can provide privacy when required.

The design of the home should therefore support both **togetherness and personal space**.

Sustainable and Affordable Interior Design

Interior improvement does not always require a large financial investment. Agricultural households can make use of locally available and affordable materials. Bamboo, natural fibres, locally produced furniture, recycled materials, and traditional crafts can be incorporated into interiors.

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Natural ventilation and daylight can reduce energy consumption. Durable furniture can reduce the need for frequent replacement. Reusing and repairing existing furniture can also help families save money.

Sustainable interior design is particularly valuable for agricultural households because it combines **economic efficiency, environmental responsibility, and practical living**.

Interior Design as a Tool for Better Resource Management

Interior design is closely related to resource management. A well-planned home can help families manage their **time, space, energy, money, and human effort** more effectively.

For example, placing cooking utensils close to the cooking area saves time. Proper storage prevents damage to food and household materials. Ergonomic workspaces reduce physical effort. Natural lighting reduces electricity use, while durable materials reduce maintenance costs.

In this way, interior design becomes more than a decorative activity—it becomes a method of managing household resources efficiently.

Conclusion

The quality of a home has a direct relationship with the quality of life of the people living in it. For agricultural households, where domestic and occupational activities are often closely connected, thoughtful interior design can make everyday life easier, safer, healthier, and more comfortable.

Good interior design does not have to be expensive or luxurious. Effective space planning, proper storage, ergonomic arrangements, natural lighting, ventilation, safety, privacy, and the use of sustainable local materials can significantly improve the living environment.

Therefore, interior design should be viewed as an important component of household well-being and resource management. By designing homes according to the actual needs, activities, culture, and resources of agricultural families, it is possible to create living environments that support not only physical comfort but also psychological well-being, family relationships, productivity, and a better overall quality of life.

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Methods for Production of Quality planting materials for high- end horticulture crops

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Selected horticultural fruit crops that are well adapted to various Agro-climatic regions, considering their potential and importance can be promoted to commercial cultivation. Production of quality planting materials is the key to achieving higher yields. Therefore, appropriate methods for producing high quality planting materials should be followed according to the specific requirements of different horticultural crops to ensure the availability of healthy vigorous and high quality planting materials.

1. KHASI MANDARIN

1.1.Assortment of mother plants for seed and bud wood

The selection of mother plants is the most crucial operation in the production of high-end planting material. Mother plants should be selected only from genuine sources with a known pedigree, considering their health, vigour, precocity, productivity, and fruit quality.

Reasonably well-matured wood from the current season's growth or from the previous season's growth should be selected as bud wood. Choose round twigs having longitudinal white streaks on the bark, with turgid buds that are ready to grow. Discard the initial, i.e., first and second, basal buds, as they are usually defective.

To prevent drying, the bud wood should be kept in damp sphagnum moss and wrapped in a gunny bag.

1.2.Assembling of seeds from scion cultivars/ rootstocks

Seeds should be selected from recommended rootstocks, selected mother plants, or cultivars. The selected trees should be free from diseases. Ripe and healthy fruits should be chosen for seed extraction. Fallen fruits are more susceptible to brown rot infection.

Seeds should be extracted from fully mature and ripe fruits by making a shallow cut through the rind around the centre of the fruit and twisting the two halves apart. The seeds are then washed in cold water and rubbed with ash to remove the adhering pulp, followed by drying under shade conditions.

Fully developed seeds, being denser, can be separated from underdeveloped seeds. To prevent *Phytophthora* infection, which can cause serious losses of seedlings in the seedbed and nursery rows, the seeds should be treated with a suitable fungicide. They should be sown immediately after extraction to obtain the highest possible germination, as the seeds are recalcitrant in nature.

1.3.Primary nursery

The primary nursery should be established either in raised beds or in plastic trays. A sterile potting mixture is preferable, as most citrus nurseries are prone to infection. A spacing of 7.5–10 cm × 2.5–3.5 cm and a sowing depth of 1–1.5 cm are recommended for nursery beds. Light irrigation using a rose can should be provided immediately after

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sowing. Germination generally occurs within 20–25 days after sowing.

1.4. Secondary nursery

The secondary nursery site should be located away from the main citrus orchards to minimize the risk of infection. A 3 × 3 m nursery bed is adequate to accommodate approximately 100 seedlings. When the seedlings attain a height of 4–6 cm and develop 8–10 leaves in the primary nursery, they should be transplanted into the secondary nursery. Seedlings that are markedly smaller or excessively tall should be discarded, and the The remaining seedlings should be treated with Ridomil (2.75 g/L) as a root-drench treatment. A fork can be used to meticulously uproot the seedlings with minimal root damage. Seedlings with hook-necked, bent, or twisted taproots should be avoided.

During the rainy season, the roots of the seedlings should be placed into holes made with sticks, and the soil around the roots should be pressed firmly to ensure better establishment.

1.4.a. Budding

During March–April, when the bark slips easily, budding is performed using the T/Shield budding technique. The bud union is wrapped with 200-gauge polythene strips measuring 1.2–1.8 cm in width. To prevent the budding union from becoming buried in the soil, budding should preferably be performed at a height of 9 cm above ground level.

The polythene strips should be removed 14–18 days after budding to promote better development of the bud sprouts. The rootstock stem should be pruned 2–4 cm above the bud union in stages, two to three times, and all side shoots should be removed.

1.5. Creation of disease – free planting material

® Containerised nursery system

® Potting mixture

® Soil solarisation

® Soil fumigation

® Stream sterilization

® Selection of seed

® Role of rootstock

1.6. Bio-diagnosis

Biological indexing should be carried out using indicator plants such as acid lime for the detection of tristeza and sweet orange for the detection of the greening bacterium.**Plant protection measures**

As a precautionary measure, nursery plants should be sprayed with Bavistin @ 1 g/L of water at monthly intervals. In case of *Phytophthora* infection, the affected plants should be removed along with their polythene bags, and the remaining plants should be treated with Ridomil MZ-72 @ 2.75 g/L or Aliette @ 2.5 g/L of water.

Nursery implements should be disinfected frequently with a sodium hypochlorite solution. The footwear of workers and visitors should be disinfected using copper sulphate and lime. The nursery floor should be regularly sprayed with a suitable copper-based fungicide, particularly at the entrance to the nursery.

Cyantraniliprole/Spinetoram :1.5-2 ml/lit water against leaf miner

Cyantraniliprole / Spinosad /Spinetoram : 0.5 ml/lit water against thrips

Chlorantraniliprole: 0.5 ml/lit water against leaf eating caterpillar

Killer 707/Imidacloprid/Acetamiprid : 1.0 ml/lit water against aphids

Abamectin/ Wettable sulphur/:0.3-0.5 ml/lit water /0.3-0.5 g/lit water against mites

Neem oil : 1.0% spray to be rotated with foliar sprays with any of the above pesticides.

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1.7. **Protocol for micropropagation of Khasi mandarin**:

Medium : Murashige and Skoog medium (1962)

Establishment : Malt extract 500 ml/l

Proliferation : Basal medium

Shooting : BAP 0.5 mg/l

Rooting : NAA 0.1 mg/l

Hardening : Sand: Soil: Soilrite @1:1:1 ratio

Pic.1 Sapling of Citrus spp.

2. GUAVA

Guava is generally propagated in India by seed. The practice is easy to adopt. Although, it has the downside of occurrence of a lot of variation among the seed propagated plants not only with reference to the productivity of the trees but also in the size, shape and quality of fruits. Moreover, seedlings have longer juvenile phase and therefore takes five to six years to blossom and produce fruits.

2.1. Sexual propagation:

Guava s mainly propagated by seed. But due to natural cross pollination, seedlings tees considerably vary in their performance. Nevertheless, it is regarded as a good method to raise rootstocks since seedlings are more sturdy.

2.2. Seed longevity:

Seeds maintain viability for many months but it is examined desirable to sow them soon after removal from the fruit. Seeds washed and dried in shade and mixed with fine wood ash are kept in tin boxes in a cool place. Guava seeds can preserve about 50% viability upto 18 months if the seeds are stored, with or without charcoal, in fastened tin can or in glass or polythene jar. Seeds could be stored for 104 days by pre-soaking in 10^{-3}M ferulic acid. Potassium nitrate 1% and para hydroxyl benzoic acid (10^{-3}) are also applicable in extending the viability of seed.

2.3. Seed Germination:

2.3. A. Seed Propagation

Guava seeds have a hard seed coat surrounding the endosperm, as a result of which an unusually long period is required for germination.

2.4. To reduce the time taken for germination:

- Boil the seeds for 5 minutes.
- Soak the seeds in water for 2 weeks and then treat them carefully with concentrated sulphuric acid.

2.5. To increase the germination percentage:

- Soak the seeds for 5 minutes in ethephon (500 ppm) and NAA, which can result in about 72% germination.

2.6. Raising of Seedlings

- Select healthy, locally available trees; true-to-type trees are preferred.
- Collect ripe fruits and clean them thoroughly.
- Extract the seeds and wash them thoroughly to remove the adhering pulp.
- Treat the seeds with a fungicide to prevent damping-off, such as Bavistin @ 3 g/L or Brassicol @ 5 g/L.
- Sow the seeds in pots or nursery beds, preferably soon after extraction.
- Seedlings can be used for grafting or budding after one year.
- Transplant the seedlings after six months to restrict root growth and reduce mortality during lifting and grafting.

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- Prune side shoots as and when they appear to obtain strong and straight rootstocks.

2.3.b. Asexual Propagation

Asexual propagation is used to obtain true-to-type plants from mother plants with high yields and good-quality fruits.

- The mother plant of a known cultivar should be true-to-type, have demonstrated high performance for several years, and be free from diseases.

2.3.b.1. Grafting: Inarching/Approach Grafting

- Inarching or approach grafting has been practiced in India for more than a century.
- Even today, it remains one of the most popular methods of guava propagation.

Advantages:

1. The technique is well known.
2. A high percentage of success can be achieved by skilled propagators.

Disadvantages:

Disadvantages of Inarching/Approach Grafting

1. The technique is relatively inconvenient.
2. It is more expensive than budding.

2.3.b.2. Veneer Grafting

- Veneer grafting has gained importance in recent years.
- Three important factors determine the success of veneer grafting:
    1. Procuring suitable scion wood.
    2. Proper cutting and preparation of scions.
    3. Selection of suitable wrapping materials and proper wrapping technique.
- Green, quadrangular, terminal shoots of the current season's growth have been found to perform better than brown, corky shoots of the previous year.
- Scions from seedless varieties have been found to be superior to those from seeded varieties.
- Grafting in April is better than grafting in March, May, or June.
- Scions that are two months old perform better than four-month-old scions.
- Scion wood should be procured 20–25 days in advance.
- Since the scions are highly succulent, they cannot be transported over long distances or stored for extended periods. Therefore, veneer grafting is unsuitable for the introduction of germplasm.

2.3.b.3. Budding

- Healthy and vigorous rootstocks should be prepared by removing side shoots up to 20–25 cm from the base.
- Budwood should be defoliated approximately two weeks in advance to induce bud swelling.
- Brown-coloured budwood with distinct leaf scars is suitable for budding.
- Younger, soft shoots with indistinct leaf scars are unsuitable.
- Budwood with waxed ends can be stored for up to seven days without difficulty.
- In seedless guava, budwood packed in moist sphagnum moss and wrapped in alkathene film, with the ends waxed, can be stored for up to 14 days at room temperature and can provide 100% bud take.
- Mother trees should be pruned during the preceding season to induce vigorous,

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succulent shoots and facilitate easy separation of buds.

- During the budding season, the buds should preferably be untied by removing the alkathene tape after two weeks rather than after three weeks.
- Soaking buds in 10 ppm IBA for 10 minutes improves the success of budding.

2.3.b.4. . Forket Budding

® 92% bud-take during Feb-Mar

Forket Budding

- Forket budding has recorded 96% success in seedless guava varieties.
- It has recorded 88% success in 'Allahabad Safeda'.

2.3.b.5. Patch Budding

- Patch budding has also shown encouraging results.
- It has recorded 88% success in seedless guava varieties.
- An 80% success rate has been reported in 'Allahabad Safeda'.
- High summer temperatures are favourable for callus formation.
- Soaking the buds in IBA @ 10 ppm for 10 minutes in 'Chittidar' resulted in the following bud-take percentages:
    - **April:** 64% bud take compared with 56% in the control.
    - **May:** 56% bud take compared with 52% in the control.

2.3.b.6. Shield Budding

- One to one-and-a-half buds should be inserted during winter or spring on young rootstocks.
- About 60% success has been reported in 'Allahabad Safeda', 'Sardar', and 'Chittidar'.
- Drying of the bud before union formation results in poor success.

2.3.b.7. Propagation by Cuttings

- The different types of stem cuttings include softwood, semi-hardwood, and hardwood cuttings.
- Guava cuttings are generally difficult to root and show varying degrees of success.

2.4. Effect of Growth Regulators

- IBA is a highly effective growth regulator for inducing rooting.
- Softwood cuttings are more responsive to growth regulators than semi-hardwood and hardwood cuttings.
- Semi-hardwood and hardwood cuttings are comparatively less responsive.
- The best period for propagation through cuttings appears to be from the end of January to May.
- Spraying mother trees with ethephon @ 50–100 ppm and treating the cuttings with IBA @ 3000 ppm can result in 100% rooting.
- IBA @ 5000 ppm induces rooting in hardwood cuttings.

2.5. Other Factors Affecting Rooting

Etiolation and invigoration, mist conditions, and phenolic compounds are among the other factors that influence the rooting of guava cuttings.

Pic.2 Sapling of Guava spp.

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3. BANANA

Banana is generally propagated using suckers. There are two main types of suckers:

3,1. Sword Suckers

- Suckers with a well-developed base and a pointed tip.
- During the early stages, they bear narrow, sword-shaped leaves.
- They are more vigorous and grow faster than water suckers.
- They come into bearing earlier.

3,2. Water Suckers

- Small, stunted suckers of superficial origin.
- They bear broad leaves.
- They generally arise near the clump from small, diseased, or injured corms.
- They are usually not produced in a healthy banana clump.
- They emerge when the plantation is too old, overcrowded, and shady, or when desuckering and general maintenance are not carried out properly.

3.3. Peepers

Peepers are newly developed maiden suckers.

Rhizomes

Rhizomes are another type of planting material used for banana propagation.

3.4. Whole Rhizomes

Whole rhizomes are used as planting material for banana propagation.

3.5. Split Rhizomes

Split rhizomes are sections of rhizomes obtained by cutting a healthy, unbunched rhizome into suitable pieces after trimming the roots. Each section should have at least one prominent, germinating eye. Very small corms or pieces of corms should be avoided, and only healthy planting material should be selected.

In the North-Eastern states with subtropical climates, particularly on hill slopes, the size of the corm can influence the rate of maturity and, consequently, the time of fruiting. The size of the corm is important because it contains reserve food that supports the early growth of the developing plant.

A rhizome weighing about 1 kg, or a well-trimmed portion of similar weight around the growing sprout, is considered ideal for planting. The use of uniform planting material tends to produce a more uniform crop that matures at approximately the same time.

In the case of 'Dwarf Cavendish', daughter rhizomes produced after harvesting the bunch can be dug out and stored under shade. After removing the portions of the pseudostem, the rhizomes can be stored for up to two months by covering them with banana leaves.

In Kerala, rhizomes of 'Nendran' are sun-dried for 2–3 days after smearing them with a paste of cattle dung and ash. They are then stored under shade for about one month before planting.

In the present context, the technique of preparing clean suckers by paring away necrotic tissues and treating them with nematicidal granules after dipping them in a mud slurry is recommended. This practice is likely to reduce nematode infestation in 'Nendran' suckers to some extent, as the cultivar is highly susceptible to nematodes, similar to Cavendish clones.

For hill bananas, such as 'Virupakshi' in Tamil Nadu, sword suckers with rhizomes of ample size,

Pic.3 Planting material of Banana

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4. PINEAPPLE

Pineapple is propagated mainly through vegetative means. In the case of hybrids, progenies developed from seeds are also subsequently propagated vegetatively. The most common planting materials used are suckers and slips. Crowns are also used, although their success rate is variable.

4.1. Suckers

Suckers emerge and develop from buds below ground level and are produced irregularly. Slips are shoots that arise from buds in the axils of leaves on the fruit stalk above ground level. Both suckers and slips resemble daughter plants growing alongside the mother plant.

Suckers emerge around the time the mother plant flowers and grow rapidly as the fruit develops. After the fruit is harvested from the mother plant, the suckers grow vigorously and produce fruit during the following season. This subsequent crop is known as the **ratoon crop**.

4.2. Slips

Slips arise from the fruit stalk. They are smaller than suckers and are produced in greater numbers per plant. Unlike suckers, they cannot develop into independent plants in situ and therefore need to be detached and transplanted into the soil.

4.3. Crowns

The crown is the leafy vegetative growth that develops at the top of the pineapple fruit and is attached to the central core of the fruit. It is called a crown because it resembles a crown adorning the apex of the fruit. Among the three main types of planting materials—suckers, slips, and crowns—suckers are the largest in size.

4.4. Other Planting Materials

Besides suckers, slips, and crowns, other planting materials include discs, hapas, and butts or stumps.

- **4.5. Discs:** Fruit stalks cut into small sections, known as discs, can also be used for propagation. However, their use under field conditions is very limited.
- **4.6. Hapas:** Hapas are shoots that develop at the base of the peduncle. They are intermediate in size between shoots and slips.

4.7. Butts or stumps: These are the portions of the plant that have borne fruit. They comprise the remaining basal portion of the plant after harvesting the fruit and removal of the upper portions, including the leaves and peduncle. Butts become less suitable as planting material as they age. They are not normally recommended for propagation and should be used only as a last resort.

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Financial Feasibility of Natural Farming

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1. Introduction

Natural farming is a chemical-free, agro-ecological approach that makes greater use of locally available farm resources, biological processes, crop diversity, mulching and livestock-linked inputs. In India, the approach is promoted as a way to reduce dependence on purchased synthetic fertilizers and pesticides and to improve farm resilience. NITI Aayog describes natural farming as a diversified system integrating crops, trees and livestock while building on natural ecological processes.

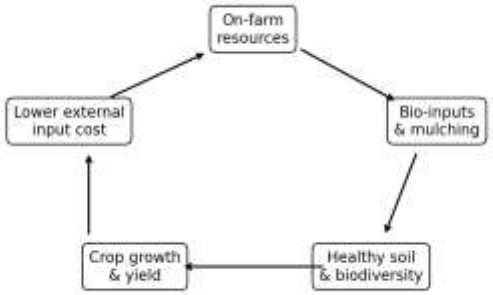
The financial feasibility of natural farming means examining whether the system can provide adequate returns after considering production cost, yield, labour, market price, risk and the value of longer-term soil and resource benefits. The central economic argument is not that natural farming always produces a higher yield, but that it can improve profitability when lower purchased-input costs and stable or improved returns compensate for any changes in yield.

2. Objectives

- To understand the major costs involved in natural farming.
- To examine how natural farming can affect gross income, net income and benefit–cost ratio.
- To identify the factors that influence its financial feasibility.
- To discuss constraints, risks and opportunities for farmers.
- To suggest measures for improving the economic viability of natural farming.

3. Major Features Relevant to Farm Economics

- Reduced dependence on purchased chemical fertilizers and pesticides.
- Preparation and use of farm-made biological inputs such as Jeevamrit and Beejamrit where locally suitable.
- Crop residue recycling, mulching and intercropping to use resources efficiently.
- Greater use of local biomass and farm resources, which can reduce cash expenditure.
- Possibility of diversified income from crops, trees, livestock and value-added products.
- Potential access to differentiated markets for chemical-free produce, although premium prices are not guaranteed.



Natural farming economic pathway

4. Components of Financial Feasibility

4.1 Cost of cultivation

The main economic advantage expected from natural farming is a reduction in paid-out input costs. Conventional crop production commonly involves purchased fertilizers, pesticides and other external

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inputs. Natural farming can replace part of these expenses with on-farm biomass, biological preparations, mulching and recycling. However, labour for preparation, application, weeding, mulching and crop management must be included when calculating the real cost.

4.2 Yield and gross returns

Financial feasibility depends on both cost and output. Gross return is generally calculated as the value of the main product plus the value of by-products or additional farm outputs. Natural farming should therefore be assessed crop by crop and season by season rather than assuming a uniform yield response.

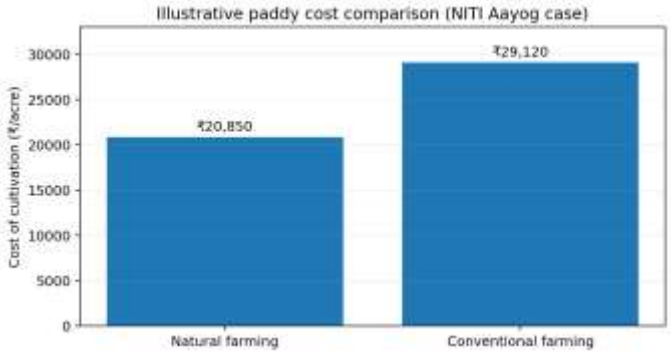
4.3 Net return and benefit–cost ratio

Net return = Gross return − Total cost of cultivation. The benefit–cost ratio (B:C ratio) is commonly used to compare economic performance. A higher ratio indicates that the value of returns is larger relative to the cost incurred. The calculation should use comparable cost concepts and include relevant labour and marketing expenses.

5. Evidence from Indian Studies

An ICAR-NAARM study covering Andhra Pradesh, Karnataka and Maharashtra found that natural farming did not consistently increase yield over conventional farming, but it could improve farmer income through lower cultivation costs and, in some cases, better prices for chemical-free produce. The study therefore highlights cost reduction and market realization as important economic pathways.

NITI Aayog's Natural Farming initiative reports examples of lower paid-out cultivation costs across several crops. In one paddy comparison presented in its training material, natural farming had a cultivation cost of ₹20,850 per acre compared with ₹29,120 under conventional farming, while the reported yields were 33.75 and 31.5 quintals per acre respectively. The corresponding net income was ₹48,000 under natural farming and ₹35,140 under conventional farming in that example. These figures are a case example, not a universal result for every farm.



Cost comparison from the paddy case reported by NITI Aayog.

6. Factors Affecting Financial Feasibility

6.1 Availability of farm resources

Feasibility is generally stronger when a farm has access to crop residues, biomass, livestock manure, water-saving practices and locally available materials. When these resources must be purchased or transported from outside, the cost advantage can become smaller.

6.2 Labour requirement

Natural farming may require additional labour during the transition period for preparing biological inputs, applying mulch, managing weeds and observing the crop. The opportunity cost of family labour and the wage rate for hired labour should be included in farm budgeting.

6.3 Market price

A premium price can improve profitability, but it should not be assumed automatically. Farmers need reliable local markets, consumer awareness, aggregation, grading, certification or appropriate claims, and reduced marketing costs to capture any price advantage.

6.4 Transition period and risk

During conversion from conventional practices, yields may vary depending on crop, soil, climate and

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management. A financial analysis should therefore consider several seasons rather than a single year. Farmers can reduce risk by adopting practices gradually, maintaining records and choosing suitable crops and enterprises.

6.5 Diversification

Intercropping, crop rotation, trees, livestock and other enterprises can spread income across different products. Diversification may also improve resource recycling and reduce dependence on one commodity price.

7. Advantages from an Economic Point of View

- Lower expenditure on purchased fertilizers and pesticides can reduce cash requirements.
- On-farm preparation of some inputs can retain more value within the farm.
- Intercropping and diversification can provide additional sources of income.
- Mulching and soil-cover practices may improve moisture conservation and resource-use efficiency.
- Improved soil biological activity and soil health may provide long-term benefits, although these benefits vary with location and management.
- Lower dependence on external inputs can reduce exposure to fluctuations in input prices.

8. Limitations and Economic Risks

- Yield response is not uniform across crops, soils and regions.
- Labour requirements can be high in some situations.
- Premium prices for chemical-free produce are not assured.
- Certification, aggregation and market access may add cost or organizational effort.
- Reliable financial records are needed to distinguish true cost savings from unpaid family labour.

9. Measures to Improve Financial Feasibility

- Prepare a crop-wise budget before adoption, including seed, labour, irrigation, biological inputs, machinery, harvesting and marketing.
- Use locally available biomass and farm residues wherever practical to reduce purchased-input expenditure.
- Adopt suitable intercropping and crop diversification to spread production and market risk.
- Maintain records of input quantities, labour hours, yield, selling price and net return for at least several seasons.
- Develop farmer groups or producer organizations for collective input preparation, aggregation, grading and marketing.
- Use soil testing and locally recommended agronomic practices to avoid nutrient deficiencies.
- Where government programmes provide training or financial support, include the actual assistance received in the farm budget without assuming that support will continue indefinitely.

10. Conclusion

Natural farming can be financially feasible when it successfully reduces purchased-input expenditure while maintaining adequate yield and obtaining a suitable selling price. Evidence from Indian studies shows that its economic advantage often comes from lower cultivation costs rather than from a guaranteed increase in yield. Therefore, financial feasibility should be evaluated using complete farm budgets, realistic labour valuation, actual market prices and multi-season records. The most suitable approach

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will differ according to crop, soil, climate, farm resources and market conditions.

Overall, natural farming should be viewed as an economic management system as well as an ecological practice. Careful planning, gradual adoption, diversification, record keeping, farmer training and market linkages can improve the chances of obtaining stable and sustainable farm income.

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Effect of Input Cost Reduction on Farm Profitability

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1. Introduction

In farming, the money spent on seed, fertilizer, pesticide, water and labour is called input cost. When the input cost is high, the farmer's profit is low.

Net profit = Income - Input cost

Natural farming is a way of growing crops using things that are easily available on the farm and in the village, like cow dung, cow urine, leaves and crop waste. It does not need costly chemicals. So, natural farming reduces the input cost and increases the profit.

2. What Is Natural Farming?

Natural farming (also called Zero Budget Natural Farming) is based on some simple principles:

- **No chemicals:** chemical fertilizers and pesticides are not used.
- **Use of local resources:** the farmer makes inputs at home from the desi cow and farm waste.
- **Living soil:** friendly microbes and earthworms make the soil fertile.
- **Soil cover:** the soil is always covered with mulch or crops.

Figure 1 shows how natural farming leads to more profit.

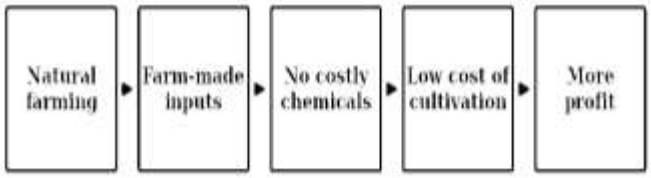

Figure 1. How natural farming increases profit

3. Four Main Practices of Natural Farming

Natural farming has four main practices, shown in Figure 2. Each one replaces a costly input.

- **Beejamrutha (seed treatment):** seeds are coated with cow dung, cow urine and lime before sowing. It protects the seed from diseases, so costly fungicide is not needed.
- **Jeevamrutha (liquid manure):** a liquid made from cow dung, cow urine, jaggery and pulse flour. It increases friendly microbes in the soil and replaces chemical fertilizer.
- **Acchadana (mulching):** covering the soil with straw or crop residue. It reduces weeds, saves water and keeps the soil cool.
- **Whapasa (soil moisture):** keeping the right mix of air and water in the soil, so the crop needs less irrigation.

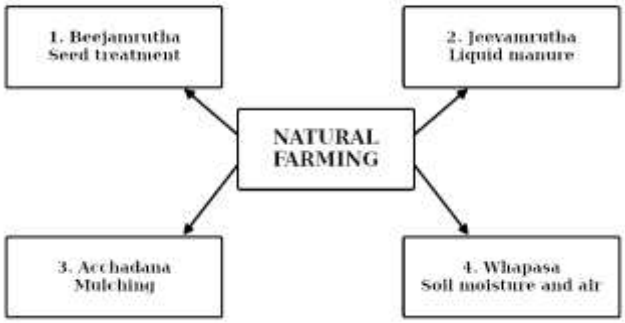

Figure 2. Four main practices of natural farming

For pest control, farmers use Neemastra and Brahmastra, which are made from neem leaves, cow urine and other local plants. They replace costly pesticides.

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Seed treatment is the easiest practice to start with. Figure 3 shows the steps of Beejamrutha.

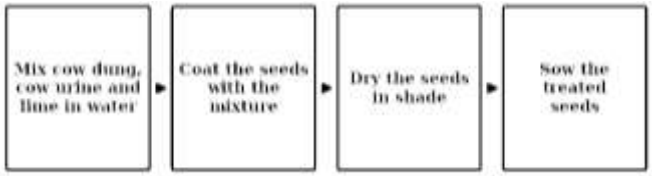

Figure 3. Steps in Beejamrutha seed treatment

4. How Is Jeevamrutha Prepared?

Jeevamrutha is the most important input in natural farming. For one acre, the farmer needs the following things:

- **Desi cow dung:** 10 kg
- **Cow urine:** 5 to 10 litres
- **Jaggery and pulse flour:** 2 kg each
- **Farm soil and water:** a handful of soil and 200 litres of water

The steps are shown in Figure 4.

Figure 4. Steps in preparing Jeevamrutha

5. How Natural Farming Reduces Input Cost

In chemical farming, most inputs are bought from the market. In natural farming, most of them are made at home. Table 1 and Figure 5 compare the two methods.

Table 1. Inputs in chemical farming and natural farming

Input	Chemical farming	Natural farming
Seed	Seed and fungicide are bought	Own seed treated with Beejamrutha
Fertilizer	Urea, DAP and potash are bought	Jeevamrutha, compost and mulching
Pest control	Costly pesticides are bought	Neemastra and Brahmastra from neem leaves and cow urine
Weed control	Weedicide or more labour	Mulching keeps weeds down
Water	Frequent irrigation	Whapasa and mulching save water

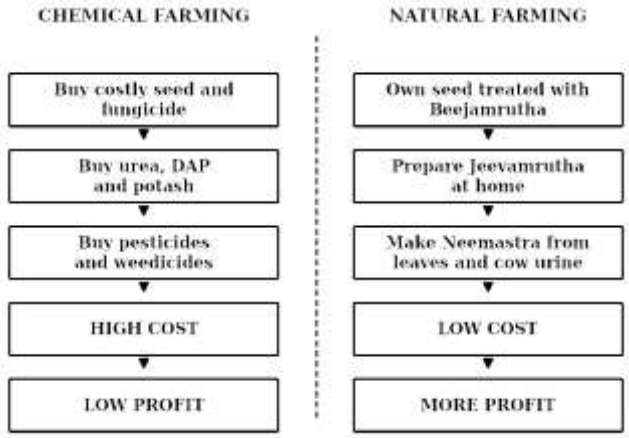

Figure 5. Comparison of chemical farming and natural farming

6. Effect on Farm Profitability

- **Lower cost:** the money that was spent on buying inputs is saved.
- **Less loan:** the farmer needs less money for inputs, so there is less need for loans and interest.
- **Higher profit:** when cost falls and the crop is sold at a fair price, the profit becomes higher.
- **Healthy soil:** the soil improves year by year, which gives a stable yield in the long run.
- **Safe food:** chemical-free produce may fetch a better price in the market.

For example, if a farmer spends Rs. 15,000 per acre on bought inputs but only Rs. 4,000 on natural inputs,

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he saves Rs. 11,000 per acre. This saving is added to his profit. (These are example figures only.) Figure 6 shows the chain of benefits.

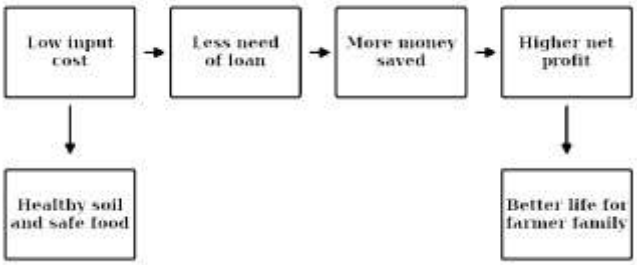

Figure 6. Benefits of low input cost

7. Simple Steps to Start Natural Farming

1. Start with a small area, such as one acre.
2. Keep a desi cow or get cow dung and urine from a neighbour.
3. Treat the seeds with Beejamrutha before sowing.
4. Apply Jeevamrutha to the crop at regular intervals.
5. Cover the soil with mulch and keep a record of your expenses.

8. Points to Remember

- **Slow start:** in the first one or two years, the yield may be slightly low while the soil is recovering.
- **Extra work:** a desi cow and some effort are needed to prepare the inputs.
- **Training:** farmers need proper training before starting natural farming.

9. Conclusion

Natural farming reduces the input cost because the farmer makes seed treatments, manures and pest sprays at home instead of buying them. The money saved is added to the profit, the need for loans becomes less, and the soil becomes healthier. Therefore, natural farming is a simple and low-cost way to make farming profitable. With training and regular practice, even small and marginal farmers can adopt it and improve their income.

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Farmer Adoption Level of Natural Farming Practices

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Introduction

Natural farming is an ecological approach to agriculture that emphasizes the use of locally available farm resources, biological processes and natural inputs for crop production. It seeks to reduce dependence on synthetic fertilizers and chemical pesticides while encouraging soil biological activity, biodiversity, recycling of farm resources and efficient use of water. Commonly discussed practices include seed treatment with natural preparations, use of Jeevamrutha and Beejamrutha, mulching, mixed cropping, intercropping and botanical or biological pest management.

The effectiveness and spread of natural farming depend greatly on the extent to which farmers adopt its practices. Adoption means more than simply knowing about a technique: it involves acceptance, actual use, regularity of use and continuation over time. Farmers may adopt one practice first and gradually add others as they gain experience and confidence. Therefore, the adoption level can vary from low to medium or high among farmers and even among different crops or regions.

Meaning of Farmer Adoption Level

Farmer adoption level refers to the degree to which a farmer accepts and implements recommended natural farming practices in the farm production system. It can be assessed through the number of practices adopted, frequency of application, area covered, consistency of use and the extent to which the farmer continues the practices across seasons.

For example, a farmer who uses only farmyard manure and crop-residue mulching may be placed in a lower adoption category, whereas a farmer who combines natural seed treatment, bio-inputs, mulching, crop diversification and botanical pest management may show a higher level of adoption. The exact classification should be based on a clearly defined scoring system in a field study.

Levels of Adoption of Natural Farming Practices

1. Low Level of Adoption

Farmers in the low adoption category use only a small number of natural farming practices and continue to depend mainly on conventional inputs. Adoption may be occasional or limited to a particular crop or part of the farm.

- Application of farmyard manure or compost.
- Use of crop residues as surface mulch.
- Occasional use of botanical pest-control preparations.
- Partial reduction in chemical fertilizers or pesticides.
- Limited preparation of natural inputs at the farm level.

Low adoption can occur when farmers have limited technical knowledge, insufficient labour or materials, uncertainty about crop performance, or strong dependence on conventional production methods.

2. Medium Level of Adoption

Farmers in the medium adoption category regularly use several natural farming practices but may still use some synthetic inputs when they consider them necessary. Such farmers generally have some

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knowledge and practical experience but have not completely shifted their production system.

- Beejamrutha or other natural seed-treatment methods.
- Regular use of Jeevamrutha or similar farm-made bio-inputs.
- Mulching and recycling of crop residues.
- Mixed cropping and intercropping.
- Botanical extracts and other non-chemical pest-management methods.
- Farmyard manure, compost and other organic materials.
- Reduced use of synthetic fertilizers and pesticides.

3. High Level of Adoption

Farmers with a high adoption level follow a wider range of natural farming practices regularly and systematically. They make greater use of locally available resources and integrate soil, crop, livestock and pest-management practices as part of the farm system.

- Regular natural seed treatment and farm-made bio-input application.
- Continuous soil cover through mulching.
- Crop diversification, mixed cropping and intercropping.
- Biological and botanical approaches to pest management.
- Recycling of crop residues and livestock wastes.
- Greater reliance on locally available farm resources.
- Reduced or minimal dependence on synthetic fertilizers and pesticides.

Factors Influencing Farmer Adoption

1. Knowledge and awareness

Farmers need practical knowledge about preparation, dosage, timing and application of natural inputs. Awareness alone may not be sufficient unless it is supported by hands-on learning.

2. Training and extension support

Field demonstrations, farmer training, extension advice and contact with experienced practitioners can help farmers understand how practices are implemented under local conditions.

3. Availability of farm resources

Natural farming often makes use of crop residues, livestock-based materials and other locally available resources. Their availability can influence whether farmers can prepare and use inputs regularly.

4. Labour availability

Some practices require labour for preparation of inputs, mulching, intercultural operations and monitoring. Labour scarcity can therefore affect adoption.

5. Economic considerations

Farmers consider input expenditure, labour costs, crop returns and the economic risk of changing production practices. Perceived savings on external inputs can encourage adoption, while uncertainty about returns may slow it.

6. Risk perception and transition concerns

Farmers may be cautious about changing established practices because crop response can vary with soil, crop, climate and management. Demonstrations and gradual adoption can help them evaluate practices.

7. Market opportunities

Availability of suitable markets, consumer demand and opportunities for differentiated produce may influence farmers' willingness to continue natural farming.

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8. Government and institutional support

Training programmes, demonstrations, technical guidance and supportive agricultural institutions can create an enabling environment for adoption.

9. Farmer experience and peer influence

Farmers often learn from their own results and from neighbouring farmers. Visible field-level experiences can influence the decision to adopt additional practices.

Measurement of Adoption Level

In agricultural extension and research, adoption can be measured by developing an adoption scale. Individual practices are listed and assigned scores according to whether and how regularly the farmer follows them. The researcher can include practices such as natural seed treatment, mulching, Jeevamrutha application, crop diversification, botanical pest management and recycling of farm residues.

One simple form of measurement is the adoption index:

Adoption Index (%) = (Score obtained by farmer / Maximum possible score) × 100

The researcher can then establish predetermined cut-off points for low, medium and high adoption. For a meaningful comparison, the same scoring method should be applied to all respondents. Frequency of practice, area covered and continuity across seasons can also be incorporated where appropriate.

Importance of Increasing Adoption

Increasing the appropriate adoption of natural farming practices can support the wider use of resource-recycling and ecological approaches in agriculture. However, adoption should be understood in relation to local soil, climate, crop, labour and economic conditions. Farmers require practical guidance to select suitable practices rather than simply adopting a large number of practices without considering their farm situation.

- Improves farmers' practical knowledge of ecological production methods.
- Encourages greater use of locally available farm resources.
- Can reduce dependence on purchased external inputs for some farm operations.
- Promotes recycling of crop and livestock resources within the farm.
- Encourages crop diversification and soil-cover practices.
- Strengthens the role of extension, demonstrations and farmer-to-farmer learning.

Conclusion

Farmer adoption is a gradual process influenced by knowledge, experience, resources, labour, economics, markets and institutional support. Farmers may begin with individual practices and gradually integrate more components of natural farming as they gain practical experience. Measuring adoption through a systematic scoring method helps researchers and extension agencies understand the extent and consistency of practice use. Strengthening farmer training, demonstrations, local resource availability and technical support can help create favourable conditions for the continued adoption of suitable natural farming practices.

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Current Scenario of Natural Farming in Different Agro-Climatic Zones of India

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Introduction

Natural farming is an ecological farming system that aims to reduce dependence on synthetic fertilizers, pesticides and other external inputs by making greater use of local biological resources, livestock, crop diversity and natural ecological processes. Important practices include mulching, crop diversification, recycling of farm residues, use of farm-based bio-inputs and maintenance of soil biological activity.

India has considerable diversity in rainfall, temperature, soil, topography and length of growing period. Under the Planning Commission classification, India is divided into 15 major agro-climatic zones. Therefore, natural farming cannot be implemented in exactly the same way everywhere; practices need to be adapted to local crops, climate, soil, water availability and farming systems.

Natural Farming in Different Agro-Climatic Zones

1. Western Himalayan Region

The Western Himalayan region includes Jammu & Kashmir, Himachal Pradesh and Uttarakhand. It has temperate to alpine conditions, mountainous terrain and many small farms. Major crops include wheat, rice, maize, pulses, vegetables and fruits. Natural farming can emphasize mulching, mixed cropping, farmyard manure, residue recycling and livestock integration. These practices can help maintain soil cover and reduce erosion on slopes. Horticulture and livestock can be integrated with natural farming, although difficult terrain, fragmented holdings and market access remain challenges.

2. Eastern Himalayan and North-Eastern Region

The Eastern Himalayan and North-Eastern region is characterized by high rainfall, rich biodiversity and hilly terrain. Rice, maize, ginger, turmeric, cardamom, tea and vegetables are important crops. Traditional and low-external-input practices provide a foundation for natural farming. Mulching, agroforestry, mixed cropping and biomass recycling are relevant. High rainfall can cause erosion and nutrient leaching, so soil cover and conservation measures are important.

3. Indo-Gangetic Plains

The Indo-Gangetic Plains include major agricultural areas of Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal. Rice-wheat systems are important. Natural farming is being explored to improve soil health and reduce dependence on purchased inputs. Crop diversification, residue management, pulses in rotations, livestock integration and efficient water management are relevant. Transition requires farmer training, demonstrations and suitable market support.

4. Central Plateau and Hill Region

This region includes large parts of Madhya Pradesh, Chhattisgarh and adjoining areas. Rice, wheat, pulses, oilseeds, millets and vegetables are important. Natural farming can be combined with livestock, biomass recycling, intercropping and moisture conservation. Rainfall variability makes mulching and water conservation particularly important.

5. Western and North-Western Dry Regions

Parts of Rajasthan, Gujarat, Haryana and Punjab experience water scarcity, high temperatures and, in

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some areas, salinity. Natural farming needs to focus strongly on water conservation and moisture retention. Millets, pulses, drought-tolerant crops, agroforestry, mulching and livestock integration can be useful. Practices should be selected according to local resource availability.

6. Southern Plateau and Hills

The Southern Plateau and Hills include parts of Karnataka, Telangana, Andhra Pradesh, Tamil Nadu and Maharashtra. Major crops include millets, pulses, oilseeds, cotton, groundnut, rice and horticultural crops. Natural farming can be integrated with crop diversification, mulching, livestock and efficient water management. Andhra Pradesh has been particularly prominent in large-scale natural farming programmes.

7. East Coast Plains and Hills

The East Coast Plains and Hills support rice, pulses, oilseeds, vegetables, coconut and horticultural crops. Natural farming can emphasize rice-based diversification, residue recycling, livestock integration and soil-moisture conservation. Cyclones, floods and coastal stresses make climate-resilient farming important.

8. Western Ghats and Coastal Region

The Western Ghats and coastal areas have humid climates, high biodiversity and substantial rainfall. Rice, coconut, arecanut, spices, plantation crops, fruits and vegetables are important. Agroforestry, mixed cropping, mulching, biomass recycling and livestock integration can fit well with diversified farms. Kerala is an important example of state-level promotion of natural farming.

Current National Scenario

The National Mission on Natural Farming (NMNF) was approved by the Union Cabinet on 25 November 2024 as a standalone Centrally Sponsored Scheme. It has a total outlay of ₹2,481 crore and promotes chemical-free, livestock-integrated and diversified farming based on traditional knowledge and scientifically supported approaches.

As reported by the Government of India in March 2026, 18,786 natural farming clusters had been formed, covering 8.80 lakh hectares, with 18.19 lakh farmers enrolled. The mission also supports Community Resource Persons, training, Bio-input Resource Centres and farmer incentives.

Major Challenges

- Yield variability during the transition period in some farming systems.
- Need for practical, crop-specific and region-specific farmer training.
- Unequal availability of livestock, biomass and other local resources.
- Limited market access and value-chain development in some areas.
- Climate variability such as droughts, floods, heatwaves and irregular rainfall.
- Need for long-term scientific evaluation and location-specific recommendations.

Future Prospects

The future of natural farming lies in developing agro-climatic-zone-specific models rather than applying one identical package throughout India. Important directions include climate-resilient natural farming, integration of crops and livestock, use of millets and pulses, soil organic matter management, water conservation, agroforestry, local bio-input production, farmer-to-farmer learning, certification and improved marketing.

Conclusion

Natural farming is increasingly becoming an important component of India's efforts toward sustainable and climate-resilient agriculture. Its expansion is supported by national programmes, farmer clusters, training, demonstrations, bio-input centres and certification initiatives. However, India's

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agro-climatic diversity means that practices must be location-specific. Combining traditional farmer knowledge with scientific research, crop diversification, livestock integration, soil and water conservation and reliable markets can help natural farming contribute to resilient and resource-efficient Indian agriculture.

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Illustrations

Figure 1. Conceptual natural farming cycle

Figure 2. Agro-climatic adaptation of natural farming

Agro-climatic setting	**Major concern**	**Natural farming emphasis**
Himalayan / hill	Erosion, slopes	Mulching, mixed farming, soil conservation
Dry / semi-arid	Water scarcity	Moisture conservation, millets, agroforestry
Indo-Gangetic plains	Input dependence	Diversification, residue recycling, livestock
High-rainfall / coastal	Floods, erosion	Soil cover, diversified systems, biomass recycling

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Natural Farming and Its Effect on Soil Physical Properties

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1.Introduction

Natural farming is a chemical-free, low-cost method of agriculture that relies on local biological resources, on-farm inputs, and natural processes instead of synthetic fertilisers and pesticides. It is closely associated with the Zero Budget Natural Farming (ZBNF) model popularised by Subhash Palekar in India, which is built around locally available cow-based preparations, mulching, and minimal soil disturbance.

The physical properties of soil — texture, structure, bulk density, porosity, water-holding capacity and infiltration — determine how well a soil can support root growth, retain moisture and resist erosion. Because natural farming changes the way organic matter, soil biology and tillage are managed, it also changes these physical properties over time. This document explains the core principles of natural farming and describes how they influence the physical condition of soil.

Soil physical health is often overlooked compared with soil chemical fertility, yet it sets the upper limit on how effectively a crop can use water and nutrients in the first place. A soil with poor structure and low porosity can hold ample nutrients and still perform poorly, because roots cannot penetrate it easily and water either runs off or drains away too fast. Understanding how a farming system affects these physical properties is therefore just as important as understanding its effect on nutrient availability.

2. Principles of Natural Farming

Natural farming is generally described using four interlinked practices, sometimes called its four pillars:

- Beejamrutha – a microbial seed treatment made from cow dung, cow urine and lime, used to protect seeds and seedlings from soil-borne pathogens.
- Jeevamrutha – a fermented culture of cow dung, cow urine, jaggery, pulse flour and soil, applied to the field to multiply beneficial micro-organisms.
- Mulching (Acchadana) – covering the soil surface with crop residue, dry leaves or standing biomass to protect it from sun, wind and heavy rain.
- Whapasa – maintaining a balance of soil moisture and air so that roots receive both water vapour and oxygen rather than saturated or bone-dry soil.

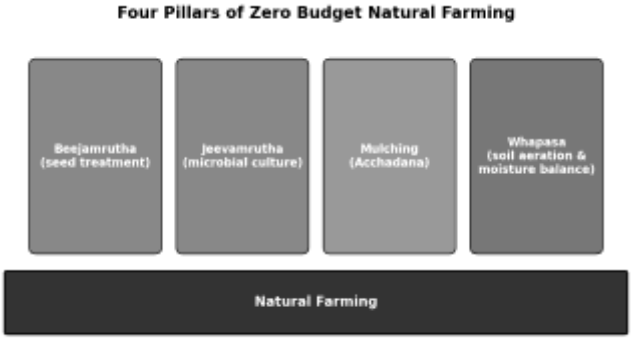

Figure 1: The four pillars of Zero Budget Natural Farming

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Together, these practices avoid soil-disturbing tillage and synthetic chemical inputs, and instead build up organic matter and microbial life in the soil. This shift in management is the main reason natural farming affects soil physical properties differently from conventional chemical-input farming.

3. Soil Physical Properties – An Overview

Soil physical properties describe the physical make-up and behaviour of soil, independent of its chemical fertility. The table below summarises the properties most relevant to farming outcomes.

Property	Meaning
Soil texture	Relative proportion of sand, silt and clay particles in the soil.
Soil structure	Arrangement of soil particles into aggregates (crumbs, blocks, granules) with pore spaces between them.
Bulk density	Mass of dry soil per unit volume; lower values generally mean looser, better-aerated soil.
Porosity	Fraction of soil volume occupied by pore spaces that can hold air or water.
Water-holding capacity	Amount of water a soil can retain after excess water has drained away.
Infiltration rate	Speed at which water enters and moves through the soil surface.
Aggregate stability	Ability of soil aggregates to resist breakdown from water, wind or tillage.

Soil texture is largely fixed by parent material and changes very slowly, but soil structure, bulk density, porosity, water-holding capacity and aggregate stability are all strongly influenced by how the soil is managed — including whether it is tilled, mulched, or fed with organic matter.

4. How Natural Farming Influences Soil Physical Properties

4.1 Mulching and Surface Protection

A continuous mulch layer shields the soil surface from raindrop impact and direct sunlight. This prevents surface crusting, keeps the topsoil looser, and reduces evaporation, which helps maintain more even soil moisture. Over time, decomposing mulch also adds organic matter that binds soil particles into stable aggregates.

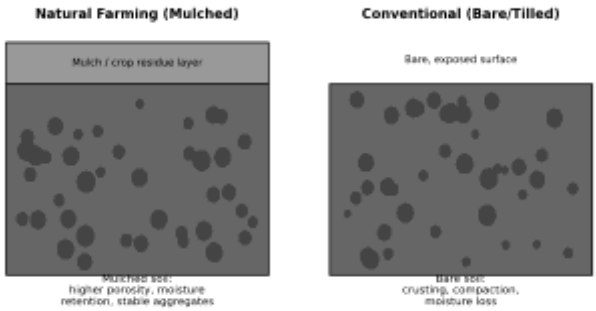

Figure 3: Simplified cross-section comparing mulched (natural farming) and bare, tilled (conventional) soil surfaces

4.2 Organic Matter and Microbial Activity

Jeevamrutha and compost-based inputs multiply soil bacteria, fungi and earthworm populations. These organisms produce sticky substances and fungal threads that bind fine soil particles into crumb-like aggregates, which in turn increases porosity and creates channels for water and air movement. Earthworm burrows, in particular, form continuous vertical channels that speed up water infiltration and allow roots to reach deeper soil layers.

4.3 Minimal Tillage

Because natural farming avoids repeated deep tillage, soil aggregates are not mechanically broken apart as often. This generally keeps bulk density lower and

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helps preserve pore continuity, which supports root penetration and water infiltration. Undisturbed soil also retains its natural layering, so biological activity built up near the surface is not repeatedly buried or exposed.

4.4 Whapasa and Moisture–Air Balance

By avoiding both waterlogging and excessive drying, the whapasa principle helps maintain a favourable ratio of water-filled to air-filled pores. This supports aerobic microbial activity, which is itself important for building and maintaining stable soil structure. Fields managed this way tend to resist the alternating extremes of crusting and cracking that are common in bare, intensively irrigated soils.

4.5 Erosion Resistance and Runoff Control

Mulch cover and stable aggregates together reduce the force of raindrop impact and slow the speed of surface runoff. Water has more time to soak in rather than carry topsoil away. Over several seasons this can reduce topsoil loss and help maintain a more uniform soil profile across a field, which is otherwise a slow but significant cost of erosion under bare cultivation.

5. Comparing Natural and Conventional Farming Soils

Field studies on natural farming plots generally report soils with lower bulk density, higher porosity, better aggregate stability and greater water-holding capacity compared with adjoining conventionally managed plots. The table and chart below summarise these general, illustrative trends.

Parameter	Conventional Farming	Natural Farming
Tillage	Frequent, intensive	Minimal or no tillage
Organic matter input	Low to moderate (chemical fertilisers)	High (mulch, compost, Jeevamrutha)
Bulk density	Comparatively higher (compaction)	Comparatively lower (looser structure)
Porosity & aeration	Reduced over time	Improved with biological activity
Aggregate stability	Weaker, prone to crusting	Stronger, crumb-type structure
Water-holding capacity	Lower, faster runoff	Higher, better retention
Microbial activity	Suppressed by agro-chemicals	Enhanced, supports aggregation

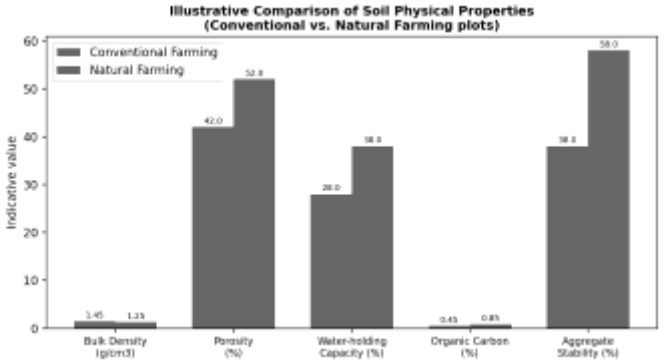

Figure 4: Illustrative comparison of soil physical properties under conventional and natural farming (indicative values)

The differences shown above are indicative of the general direction reported in field trials rather than fixed universal values, since actual figures depend on soil type, climate, crop and the number of years under natural farming management. Even so, the consistent direction of change — lower bulk density, higher porosity, and better water retention and aggregate stability — is a useful summary of what natural farming tends to do to a soil's physical condition over time.

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6. Advantages and Limitations

6.1 Advantages

- Improves long-term soil structure and reduces compaction.
- Increases water retention, which can help crops cope with dry spells.
- Lowers input costs since fertilisers are replaced by on-farm preparations.
- Supports beneficial soil organisms and biodiversity.

6.2 Limitations

- Benefits to soil structure build up gradually and are not immediate.
- Requires reliable access to cattle products and consistent preparation of inputs.
- Yield response during the transition period can be variable and needs local validation.

7. Practical Notes for Getting Started

Farmers wishing to observe these soil physical benefits on their own fields can begin with a few manageable steps rather than adopting every practice at once:

- Start mulching a portion of the field with available crop residue or dry leaves before the dry season, and compare soil moisture retention with an unmulched patch.
- Prepare and apply Jeevamrutha at regular intervals rather than as a one-time input, since microbial populations need continuous organic feeding to build up.
- Reduce tillage depth and frequency gradually, monitoring for surface crusting or waterlogging as the soil adjusts.
- Keep a simple field record of infiltration time (how quickly a measured amount of water soaks in) each season as a low-cost way to track structural improvement.

These steps make it possible to observe changes in soil physical condition directly, in addition to relying on the general trends reported in published studies. Because soil structure changes gradually, it is best to compare the same field over several consecutive seasons rather than expecting a visible difference within a single crop cycle.

8. Conclusion

Natural farming influences soil physical properties mainly through mulching, reduced tillage, and the addition of microbially active inputs such as Jeevamrutha. These practices tend to lower bulk density, raise porosity and water-holding capacity, and improve aggregate stability compared with intensively tilled, chemically managed soils. While the underlying soil texture does not change, soil structure and related physical properties can improve steadily under sustained natural farming management, supporting healthier root growth and better resilience to moisture stress.

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Farmers' adoption of natural pest management

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Introduction

Agriculture is an important source of food, employment and income. Crop pests such as insects , mites, diseases and nematodes can reduce crop yield and quality. Synthetic pesticides provid quick control, but repeated and indiscriminate use may cause pesticide residues, resistance, harm to beneficial organisms and environmental pollution. Natural pest management offers a more sustainable alternative by using ecological, biological, botanical, cultural and physical methods.

Natural pest management does not mean allowing pests to damage crops. Its main idea is to maintain pest populations below economically damaging levels while conserving the natural balance of the farm ecosystem. It can be combined with Integrated Pest Management (IPM), where farmers monitor the crop and select suitable control measures according to the pest situation.

Meaning and Objectives

Natural pest management is the use of naturally occurring organisms, plant-derived materials,cultural practices and physical methods to suppress crop pests. Its objectives are to reduce unnecessary pesticide use, conserve natural enemies, protect soil and water, maintain biodiversity, reduce production risks and support safe and sustainable crop production.

Example : Ladybird beetle feeding on aphids – an example of biological control.

Major Natural Pest Management Practices

Biological control: Predators, parasitoids and microbial agents can suppress pests. Example include ladybird beetles, lacewings, parasitoids such as Trichogramma and microbial agents such as *Bacillus thuringiensis* and *Beauveria bassiana*.

Botanical pesticides: Plant-based materials such as neem preparations can be used against suitable pests. Their use should follow crop-specific recommendations and correct application practices.

Cultural practices: Crop rotation, timely sowing, field sanitation, removal of infested plant parts,balanced nutrition and proper irrigation can make crop conditions less favourable for pest multiplication.

Mechanical and physical methods: Hand-picking, traps, sticky traps, barriers and removal of pest-infested plant parts are useful, especially when pest populations are low and fields can be monitored regularly.

Farmers' Adoption of Natural Pest Management

Adoption means the process through which farmers become aware of a practice, evaluate it, try it and continue using it when they find it useful. Farmers do not adopt a technology only because it is environmentally friendly. They also consider cost, effectiveness, labour, availability of inputs, risk of crop loss and advice from trusted agricultural sources.

Factors Influencing Adoption

Awareness and knowledge: Farmers need to identify pests and beneficial organisms correctlyband

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understand when natural control methods are suitable.

Economic factors: Farmers consider input cost, labour requirement, expected yield and market price. Affordable practices are more likely to be adopted and continued.

Availability of inputs: Quality bio-control agents, botanical products, traps and suitable seeds must be available at the right time.

Extension and technical support: Agricultural extension officers, universities, research institutions and farmer organisations can provide training, demonstrations and field-level advice.

Farmers' experience: Successful results observed in a farmer's own field or neighbouring farms can increase confidence and encourage wider adoption.

Pest pressure: During severe outbreaks, farmers may prefer rapid-acting control. Preventive practices and regular monitoring can reduce the need for emergency pesticide applications.

Market demand and policy support: Demand for safer and sustainably produced food, along with suitable institutional support, can create additional motivation for adoption.

Neem-based botanical pesticide

Azadirachta indica Neem-based botanical pest management – a plant-derived approach used in sustainable agriculture.

Benefits of Adoption

Natural pest management can reduce unnecessary dependence on synthetic pesticides and support conservation of beneficial organisms. Biological control agents such as predators, parasitoids and microbial organisms can provide targeted pest suppression. Cultural and mechanical methods can often be integrated with normal farm operations. Together, these practices can contribute to better ecosystem health and more sustainable crop production.Another important benefit is support for Integrated Pest Management. Instead of routine spraying, farmers can monitor pest populations and use control measures when intervention is justified. This approach can help protect beneficial insects and may reduce the risk of pesticide resistance when chemical treatments are still needed.

Constraints in Adoption

The major constraints include limited awareness, difficulty in identifying pests and natural enemies,insufficient practical training, uncertain or slower results from some methods, limited availability of quality bio-inputs, labour requirements and fear of crop loss during serious pest outbreaks. Farmers may also hesitate when they do not have reliable technical support or a nearby source of suitable inputs.

Strategies to Improve Adoption

1. Conduct regular farmer training on pest identification, monitoring and natural control methods.

2. Establish demonstration plots and farmer field schools.

3. Improve timely availability and quality of bio-control agents and botanical products.

4. Encourage farmer-to-farmer learning and local success stories.

5. Provide simple, crop-specific extension advisories.

6. Promote integrated approaches rather than dependence on a single control method.

7. Strengthen links among farmers, extension agencies, research institutions and input suppliers.

Role of Agricultural Extension

Extension services are important for converting scientific recommendations into practical field-level action. Demonstrations, training programmes, mobile advisories, field visits and farmer meetings can improve knowledge and confidence. Extension workers can also help farmers distinguish pests from

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beneficial organisms and select appropriate management options.

Conclusion

Farmers' adoption of natural pest management is essential for sustainable crop production. Natural pest management combines biological control, botanical products, cultural practices, mechanical methods, resistant varieties and conservation of beneficial organisms. Adoption depends on knowledge, economic feasibility, availability of inputs, technical guidance and farmers' confidencein the results.

Greater adoption can be achieved through practical demonstrations, strong extension support, quality bio-inputs, farmer participation and suitable institutional policies. The most effective approach is not simply to replace every chemical pesticide with one natural product, but to use monitoring, prevention and multiple compatible methods as part of an Integrated Pest Management programme . Such an approach can help farmers protect crops while conserving the health of the agricultural ecosystem.

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Effect of Mulching on Soil Health and Natural Farming

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Introduction

Mulching is the practice of covering the soil surface around plants with organic or inorganic materials. Common organic mulches include straw, dry leaves, crop residues, grass, compost and farmyard materials. In natural farming, locally available plant residues are generally preferred because they protect the soil while gradually returning organic matter to it. Soil is a living system containing minerals, organic matter, air, water and many organisms. Continuous exposure of bare soil to strong sunlight and heavy rain can increase evaporation, erosion and loss of soil quality. Mulching provides a protective cover and helps maintain a better environment for roots and soil organisms.

1.Meaning and Types of Mulching:

Mulch is any material placed on the soil surface to reduce direct exposure of soil. Mulching may be broadly divided into organic and inorganic mulch.

- Organic mulch:, compost straw, dry leaves, grass clippings, crop residues, husks and other biodegradable materials
- Inorganic mulch: plastic sheets, stones, gravel and other non-biodegradable materials.

  For natural farming, organic residues are particularly useful because they decompose and contribute carbon and nutrients to the soil. Mulch should be free from harmful contaminants and, where possible, obtained from healthy crop residues

2. Effects of Mulching on Soil Health :

a) Soil moisture conservation: Mulch reduces direct evaporation from the soil surface. It also improves infiltration and helps water remain available to plants for a longer period.

b) Temperature regulation: A mulch layer reduces rapid heating during hot periods and reduces sudden temperature changes at the soil surface. This provides a more stable environment for roots and microorganisms.

C) Reduction of soil erosion: Mulch protects soil particles from the direct impact of raindrops and slows surface runoff. This helps reduce the removal of fertile topsoil.

d) Addition of organic matter: Organic mulch gradually decomposes and adds organic matter to soil. This can improve soil aggregation contribute to nutrient cycling.

e) Improvement of soil structure: Increased organic matter can help improve aggregation, porosity and water-holding characteristics of soil.

3.Effect on soil microorganisms and nutrient cycling:

Healthy soil contains bacteria, fungi, earthworms and other organisms. Organic mulch supplies carbon-containing materials and creates a cooler, moist surface environment that can support biological activity. As residues decompose, nutrients are gradually released and become part of the soil nutrient cycle. Decomposition is carried out by soil organisms. The speed of decomposition depends on the type of residue, moisture, temperature and

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carbon-to-nitrogen ratio. Properly managed mulch therefore supports the biological processes that maintain soil fertility.

4. Weed Management:

A thick mulch layer can reduce the amount of light reaching weed seeds and can physically suppress weed emergence. This reduces competition between weeds and crops for water, nutrients and space. However, mulch should not be placed directly against the plant stem in a way that creates excessive moisture and disease problems

5. Mulching in Natural Farming:

Natural farming aims to maintain soil cover, recycle farm resources and encourage biological processes rather than depending heavily on external synthetic inputs. Mulching fits these principles because crop residues and other locally available biomass can be returned to the field.

In natural farming, mulch can be used to keep soil covered, conserve moisture, reduce erosion and provide food for soil organisms.Maintaining soil cover is especially important during periods of high temperature or rainfall.

6. Benefits of Mulching in Natural Farming:

- Conserves soil moisture and reduces evaporation
- Protects topsoil from erosion and runoff
- Adds organic matter when biodegradable materials decompose
- Supports soil microorganisms and nutrient cycling
- Helps maintain more favourable soil temperature
- Suppresses weeds and reduces repeated weeding work
- Improves soil aggregation and physical condition over time
- Encourages recycling of crop residues within the farm
- Can reduce dependence on purchased inputs when suitable farm residues are available.

7. Suitable Materials for Natural-Farming Mulch

Farm residues such as paddy straw, dried weeds without mature seeds, fallen leaves, grass, sugarcane trash and other clean plant residues can be used. The material should be spread evenly and should not contain harmful chemicals, diseased plant material or invasive weed seeds.

8. Proper Method of Mulching:

First remove excessive weeds where necessary and ensure the soil has adequate moisture. Spread organic material as a loose, even layer around the crop. Keep a small gap around the stem to improve air movement and reduce stem-rot risk. Replenish the mulch when it becomes too thin because of decomposition or movement by wind and rain. The appropriate thickness depends on crop, material and local conditions. Very thin mulch may not give enough protection, while excessively thick or wet mulch can restrict aeration and may encourage pests or diseases.

9. Limitations and Precautions:

Mulching is beneficial when properly managed, but it is not a substitute for all other soil-management practices. Organic mulch can temporarily tie up nitrogen during decomposition when high-carbon residues are incorporated or placed in certain conditions. Some mulch materials may also harbour pests or pathogens if they are contaminated. Plastic mulch can create disposal and environmental problems if it is not properly collected and recycled. Important precautions include:

- Use clean and suitable organic material
- Avoid diseased residues when they may spread crop diseases
- Keep mulch away from direct contact with the plant stem

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- Maintain adequate but not excessive thickness
- Monitor soil moisture, pests and crop growth regularly
- Manage plastic mulch responsibly where it is used

10. Overall Effect on Soil Health:

The main soil-health effect of mulching is the protection of the soil surface. By conserving moisture, reducing erosion, moderating temperature and supplying organic matter, organic mulch can contribute to improved physical, chemical and biological soil properties. Its benefits increase when combined with other good soil-management practices such as crop rotation, residue recycling and maintenance of living roots.

11. Conclusion :

Mulching is a simple and useful practice for improving soil health. In natural farming, the use of locally available organic residues helps maintain soil cover, conserve water, reduce erosion, suppress weeds and support soil biological activity. Proper selection and management of mulch are important to obtain these benefits. Therefore, mulching can be an important component of sustainable natural-farming systems.

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Constraints in the Development of Natural Farming

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Introduction

Natural farming is all about growing crops the way nature intended, completely avoiding artificial chemicals like synthetic fertilizers or toxic pesticides. Instead, it relies on natural alternatives like earthworms, compost, and cow manure to keep the soil alive and healthy.

Natural farming is a sustainable agricultural practice that mimics natural ecosystems by eliminating synthetic fertilizers, chemical pesticides, and heavy tillage, relying instead on biodiversity, natural nutrient cycling, and on-farm resources. While it offers significant environmental and long-term economic benefits, transitioning to and maintaining this system presents several practical challenges.

Even though this method sounds perfect for the environment and helps save money on expensive farm chemicals, switching to it in real life is actually pretty difficult. Farmers face a lot of real-world hurdles that prevent natural farming from becoming mainstream.

1. The Shock of Low Yields During Transition

One of the biggest roadblocks is the drop in crop yields during the transition phase. When a piece of land has been hooked on chemical fertilizers for decades, the soil loses its natural strength.

If a farmer suddenly stops using chemicals, the crops don't grow well at all for the first two or three years. Most regular farmers simply cannot afford to take a financial hit or risk a poor harvest while waiting for the soil to heal itself.

2. High Demand for Manual Labor

Another massive issue is how much physical work it takes. Without chemical weedkillers, someone has to pull out weeds by hand, which takes hours of backbreaking labor.

Preparing natural mixtures like beejamrit or jeevamrit (natural soil boosters) requires daily effort, collecting fresh cow dung and urine. Since a lot of young people are moving away from villages to find office jobs in cities, finding enough workers to handle this heavy manual labor is getting harder every day.

3. Lack of Proper Knowledge and Training

We also have to look at the massive gap in knowledge and proper training. Most farmers today grew up learning only about chemical farming, so they don't know how to manage pests or plant diseases using purely natural methods.

It takes a lot of time to learn which beneficial insects eat the bad pests, and there just aren't enough government experts going out to villages to teach these techniques.

4. Severe Shortage of Raw Materials

On top of that, there is a severe shortage of raw materials. To make natural inputs, you need a lot of cattle to get enough manure and urine for the fields.

Since many modern farms have mechanized and don't keep local desi cows anymore, sourcing these materials is a constant struggle.

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Even finding pure, untreated organic seeds is a headache, as almost everything available in local shops is pre-treated with chemical fungicides.

5. Water and Irrigation Issues

Water management is another hidden constraint that people rarely talk about. Natural farming relies heavily on maintaining soil moisture through mulching (covering the soil with organic matter).

However, if a farmer lives in a drought-prone area with poor irrigation facilities, keeping the soil covered and damp enough for microbes to survive becomes nearly impossible.

6. Social Pressure and Neighborhood Taunts

Social pressure from the farming community also plays a big role. Farming is a very community-driven activity.

When a single farmer tries to switch to natural farming, their fields might look a bit messy or full of weeds compared to the perfectly clean, chemical-sprayed fields next door.

Neighbors often mock them or blame their natural fields for spreading pests to nearby lands, which creates a lot of mental stress and pushes them to go back to chemicals.

7. Marketing and Costly Certification Traps

Lastly, selling the final harvest is a major hassle. There aren't many dedicated markets or supply chains for natural produce, especially in rural areas.

Regular consumers in local markets just want the cheapest vegetables and usually refuse to pay extra for naturally grown food.

To make things worse, getting an official "organic" or "natural" certificate to prove the food is clean costs a lot of money and involves endless paperwork, which small farmers just don't have the time or money to handle.

Conclusion

In conclusion, while natural farming is a fantastic idea for saving our environment and improving health, it is not easy for a regular farmer to just switch over. The lack of extra labor, the initial drop in food production, social pressure, and the struggle to find good markets make it a huge gamble.

For natural farming to actually grow, governments need to step up and give farmers financial support during the tough transition years, along with proper practical training and guaranteed fair pricing in the markets.

Natural farming, while highly sustainable and ecologically sound, faces several critical constraints that hinder its widespread adoption among mainstream farmers. These limitations generally fall into technical, economic, and institutional categories.

In conclusion, natural farming offers a powerful path toward long-term environmental sustainability, climate resilience, and reduced input costs for farmers. However, it cannot be treated as an overnight solution. To successfully overcome its constraints—such as initial yield drops and high labor demands—farmers require targeted institutional support.

For natural farming to scale globally, governments and agricultural bodies must provide structured financial incentives during the transition phase, robust local training networks, and dedicated market channels that reward farmers for safeguarding the ecosystem.

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Integrated Weed Management And Sustainable Crop Production

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Introduction

Agriculture is the main source of food, raw materials, and income for many people. Crop production is affected by several factors, such as pests, diseases, weeds, and climate change. Among these, weeds are one of the major problems that reduce crop yield and quality.

Weeds are unwanted plants that grow along with cultivated crops. They compete with crops for water, nutrients, sunlight, and space. Effective weed management is essential for improving crop growth, increasing yield, and maintaining soil health.

Integrated Weed Management (IWM) is an approach that combines different weed control methods to manage weeds effectively, economically, and sustainably.

2. Definition of Integrated Weed Management

Integrated Weed Management is the combination of cultural, mechanical, biological, and chemical methods to control weeds and reduce their harmful effects on crop production.

3. Objectives of Integrated Weed Management

• To control weeds effectively.

• To reduce crop yield losses caused by weeds.

• To maintain soil fertility and soil health.

• To reduce excessive use of herbicides.

• To protect the environment and biodiversity.

• To improve the sustainability of crop production.

• To reduce the development of herbicide-resistant weeds.

4. Importance of Weed Management

Weed management is important because weeds compete with crops for essential resources.

Uncontrolled weeds can reduce crop growth, affect harvesting, and act as hosts for pests and diseases.

Proper weed management helps farmers achieve better crop establishment, higher productivity, and efficient use of water and nutrients.

Methods Of Integrated Weed Management

Integrated Weed Management uses different control methods together. The main methods are cultural, mechanical, biological, and chemical weed management.

1. Cultural Weed Management

Cultural weed management involves agricultural practices that reduce weed growth and improve crop competitiveness.

Methods:

• Crop rotation: Growing different crops in successive seasons to disrupt weed growth and life cycles.

• Proper sowing time: Selecting suitable sowing time to encourage crop growth and reduce weed competition.

• Optimum plant spacing: Maintaining suitable spacing so that crops can compete with weeds.• Use of clean seeds: Using weed-free seeds to prevent the spread of weed seeds.

• Competitive crop varieties: Selecting vigorous varieties that suppress weeds.

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• Cover crops: Growing crops that cover the soil surface and reduce weed emergence.

Advantages:

• Reduces weed infestation.

• Improves crop growth.

• Maintains soil health.

• Reduces dependence on herbicides.

2. Mechanical and Physical Weed Management

Mechanical weed management involves the physical removal or destruction of weeds.

Methods:

• Hand weeding – Removing weeds manually using hands.

• Hoeing – Removing weeds using a hand hoe.

• Tillage – Preparing the soil to control emerging weeds.

• Intercultivation – Removing weeds between crop rows.

• Mowing – Cutting weeds to prevent seed production.

• Mulching – Covering the soil with organic or suitable materials to suppress weeds.

Advantages and limitations:

• Reduces weed competition and is useful in many farming systems.

• Requires labour and time.

• Repeated operations may be necessary.

• Improper tillage can increase soil erosion.

3. Biological Weed Management

Biological weed management uses living organisms or their activities to suppress weeds. Examples include insects that feed on specific invasive weeds, suitable plant pathogens, and competitive crops. Biological control must be carefully selected to avoid harm to cultivated crops and native ecosystems.

Chemical Weed Management And Sustainable Crop Production

4. Chemical Weed Management

Chemical weed management involves the use of herbicides to control weeds. Herbicides are chemicals used to kill or suppress unwanted plants.

Types of herbicides:

• Selective herbicides: Control certain weeds without causing unacceptable injury to the intended crop when used correctly.

• Non-selective herbicides: Control a wide range of plants and require careful application to avoid crop damage.

• Pre-emergence herbicides: Applied before weeds emerge from the soil.

• Post-emergence herbicides: Applied after weeds have emerged.

Advantages:

• Saves labour and time.

• Controls weeds effectively when properly selected.

• Useful for managing weeds in large agricultural fields.

Precautions:

• Use only recommended herbicides for the specific crop and weed.

• Follow label instructions and application rates.

• Avoid spray drift onto neighbouring crops and water bodies.

• Use suitable protective equipment as directed on the product label.

• Use diverse weed management practices to reduce herbicide resistance.

5. Meaning of Sustainable Crop Production

Sustainable crop production is the production of crops in a way that meets present food needs while protecting natural resources and maintaining productivity for future generations. It balances economic, environmental, and social needs.

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6. Principles of Sustainable Crop Production

• Soil health management: Maintaining soil fertility and preventing degradation.

• Water conservation: Using irrigation water efficiently.

• Biodiversity conservation: Protecting beneficial organisms and natural ecosystems.

• Efficient nutrient management: Applying nutrients according to crop requirements.

• Integrated pest and weed management: Combining suitable methods to reduce unnecessary chemical use.

• Climate-resilient farming: Adopting practices that help crops cope with changing climatic conditions.

7. Relationship Between IWM and Sustainable Crop Production

Integrated Weed Management supports sustainable crop production by reducing weed competition while promoting efficient use of resources. Crop rotation, mulching, timely mechanical weeding, and appropriate herbicide use can work together to control weeds and conserve soil and water.

Benefits, Challenges, And Conclusion

8. Benefits of Integrated Weed Management

A. Environmental Benefits

• Reduces unnecessary dependence on herbicides.

• Helps protect soil and water resources.

• Supports beneficial organisms and biodiversity.

• Reduces the risk of weed resistance when diverse methods are used.

B. Economic Benefits

• Reduces weed-related crop yield losses.

• Improves the efficiency of farm inputs.

• Can reduce long-term weed control costs.

• Improves crop productivity and farm income when implemented effectively.

C. Agricultural Benefits

• Improves crop establishment and growth.

• Reduces competition for nutrients, water, and sunlight.

• Supports better crop quality.

• Helps prevent the spread of problematic weeds.

9. Challenges of Integrated Weed Management

Lack of knowledge about different weed control methods.

• Higher labour requirements for some mechanical methods.

• Initial costs of equipment and mulching materials.

• Difficulty in controlling persistent or invasive weeds.

• Need for proper timing and planning.

• Herbicide resistance caused by repeated use of the same mode of action.

Training, extension services, and locally suitable management plans can help farmers overcome these challenges.

10. Role of Farmers in Sustainable Weed Management

• Identify weeds correctly before selecting control methods.

• Use clean seeds and maintain proper field sanitation.

• Adopt crop rotation and cover crops where suitable.

• Combine cultural, mechanical, biological, and chemical methods.

• Follow safe herbicide application practices.

• Monitor fields regularly and control weeds at the right stage.

11. Conclusion

Integrated Weed Management is an important approach for sustainable crop production. It

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combines different weed control methods to reduce crop losses, protect natural resources, and improve farm productivity. By adopting suitable IWM practices, farmers can manage weeds effectively, reduce environmental risks, and maintain agricultural production for future generations.

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Effect of Natural Farming in Crop Yield

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Introduction

Natural farming is an agricultural system that aims to grow crops with minimum dependence on externally purchased synthetic fertilizers, pesticides and other chemical inputs. It emphasizes the use of locally available natural resources, biological processes and ecological principles to maintain soil fertility and crop productivity. Natural farming is closely associated with practices such as the use of farm-made organic preparations, mulching, crop diversification, recycling of crop residues and maintaining beneficial organisms in the soil.

Crop yield is one of the most important factors considered when evaluating any farming system. The effect of natural farming on yield can vary according to crop, soil type, climate, management practices and the length of time the system has been followed.

In some situations, natural farming can maintain or improve yield, particularly over the long term, while during the initial transition period yields may be lower in some crops.

Natural Farming (also known as Zero Budget Natural Farming or ZBNF) is a regenerative, chemical-free agricultural practice that prohibits synthetic fertilizers and pesticides. It relies on four main pillars: Beejamrit (seed treatment), Jeevamrit (microbial inoculant from cow dung and urine), Acchadana (soil mulching), and Whaapasa (moisture management).

At the center of the global debate surrounding its widespread adoption is its direct impact on crop yield, a critical metric for global food security and farming livelihoods

Principles of Natural Farming

1.Minimum external inputs:Dependence on synthetic fertilizers and pesticides is reduced.

2.Soil health management:Soil organisms and natural nutrient cycles are encouraged.

3.Use of farm resources:Crop residues, animal wastes and locally available materials are recycled.

4.Mulching:Plant residues and other suitable materials are used to cover the soil.

5.Crop diversification:Different crops may be grown together or in rotation to improve ecosystem stability.

6.Biological pest management:Beneficial insects and natural enemies are conserved.

7.Water conservation:Practices that improve soil moisture retention and reduce evaporation are encouraged.

8.Year-Round Soil Cover: Keep the ground covered with living crops or organic mulch (residues and leaves) to protect against erosion and retain moisture.

9.Crop Diversity: Grow multiple, diverse crops (multicropping) rather than single-crop monocultures to build system resilience.

10.Livestock Integration: Incorporate cattle or other farm animals to use natural manure and urine for recycling biomass and boosting soil biology.

Effect of Natural Farming on Crop Yield

1.Effect on Soil Fertility

Soil fertility plays an important role in crop yield. Natural farming practices encourage biological activity in the soil. Organic residues and natural

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inputs provide substrates for microorganisms, which contribute to nutrient cycling.

2.Effect on Nutrient Availability

Crops require nutrients such as nitrogen, phosphorus, potassium, sulphur and micronutrients for proper growth. Natural farming attempts to improve nutrient cycling through biological activity, crop residues, livestock integration and other farm-based resources.

3.Effect on Water Use and Moisture Conservation

Mulching and maintenance of soil cover are important natural farming practices. They can reduce direct evaporation from the soil surface and protect the soil from excessive heating and erosion.

4.Effect on Yield Stability

One important potential advantage of natural farming is improvement in the resilience of the farming system. Practices such as soil cover, crop diversification and improved moisture conservation may help crops cope with environmental stresses.

Yield stability is particularly important for farmers because a farming system that produces reasonably consistent yields under variable weather conditions can reduce production risks.

5.High-Nutrient Demanding Crops (Paddy & Sugarcane): Some multi-year studies have noted substantial initial yield drops (up to 20% or more) in crops like paddy rice and sugarcane when transitioned abruptly without sufficient organic matter supplements. However, performance improves when farmyard manure is integrated.

Factors affecting yield under Natural Farming

1.Soil Microbial Activity and Health: High populations of soil bacteria, fungi, and earthworms enhance nutrient mineralization and availability.

2.Transition Phase Instability: Yields often drop during the initial seasons as the soil ecosystem adjusts away from synthetic chemicals before stabilizing over time.

3.Mulching and Moisture Retention: Constant soil cover and organic mulching keep soil cooler and retain water, directly supporting better resilience and growth.

4.Quality of Bio-Inputs: The consistency and proper preparation of natural microbial inoculants (such as Jeevamrit and Beejamrit) dictate nutrient availability.

5.Agroecological Context: Performance varies significantly by region, local climate, soil type, and specific crop varieties.

6.Farmer Knowledge and Skill: Labor-intensive management practices require deep understanding of local crop cycles and pest-antagonistic microbial interactions.

7.Biologically Mediated Pest Resistance:Pest and disease control relies on competitive and antagonistic microbial interactions rather than synthetic chemicals, making overall farm biodiversity a critical buffer against major crop losses.

8.Natural farming relies on minimum soil disturbance, constant soil cover, and living root systems to boost soil organic carbon (SOC).

9.Increased microbial activity and enzyme systems (dehydrogenase, phosphatase, and urease) accelerate nutrient mineralization and improve nutrient use efficiency.

10.Improved soil aggregation, porosity, and water-holding capacity protect crops better against drought stress.

Advantages of Natural Farming Related to Crop Production

1.It Helps maintain soil biological activity

2.Reduces dependence on synthetic agricultural inputs.

3.Encourages recycling of farm resources.

4.Can improve soil structure and moisture conservation.

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5.May reduce input costs when farm-made resources are readily available.

6.Encourages biodiversity in agricultural ecosystems.

7.Supports conservation of beneficial insects and soil organisms.

8.May improve long-term sustainability of agricultural production.

9.Can contribute to better resilience under certain environmental stresses.

10.Encourages environmentally friendly agricultural practices.

Limitations of Natural Farming

First, crop yield may decline during the initial transition period in some situations. Farmers accustomed to conventional fertilizer recommendations may need new knowledge and management skills.

Second, nutrient supply can become a concern if the nutrients removed through harvested crops are not adequately replaced. Therefore, nutrient cycling and soil fertility management are important.

Third, the effectiveness of natural farming practices can vary according to location, crop and management conditions. A practice that works well in one region may not produce the same result elsewhere.

Farmers may also require training in biological pest management, crop diversification, soil management and preparation of farm-based inputs.Because synthetic chemical pesticides and fast-acting remedies are completely excluded, natural farming relies strictly on preventive bio-formulations. If a severe pest outbreak or highly aggressive plant disease occurs, these natural alternatives can sometimes fall short, leading to sudden crop losses.Natural farming relies heavily on biological nitrogen fixation and nutrient weathering. For high-yielding, nutrient-hungry crops (like hybrid paddy or sugarcane), natural inputs may not always release macronutrients (especially nitrogen and phosphorus) rapidly enough during peak crop growth stages.

Long-Term Effect on Sustainable Crop Yield

The long-term sustainability of crop production depends heavily on soil health, water availability and ecological balance. Natural farming focuses on these factors rather than only on short-term production.Maintaining soil cover, recycling biomass and encouraging biological activity can contribute to the development of a healthier agricultural ecosystem. If nutrient supply is adequate and crop management is appropriate, these practices may support sustainable crop production.Thus, natural farming should be considered as a system of farm management rather than simply replacing chemical fertilizers with natural products.In the long term, Natural Farming (NF) fundamentally shifts the farm from an input-dependent system to a self-sustaining ecosystem. While conventional farming often faces yield stagnation over time due to soil degradation, natural farming demonstrates a U-shaped curve: a temporary drop in the initial years, followed by long-term yield stabilization and climate resilience as the soil microbiome recovers.

Conclusion

The long-term impact of Natural Farming (NF) on crop yield can be summarized by a transition-to-stabilization trajectory. While the system often triggers an initial yield drop of 15% to 25% during the first 3 years as the soil recovers from chemical dependency, it ultimately delivers highly resilient, stable, and sustainable yields over time. By rebuilding the soil microbiome, increasing soil organic carbon, and enhancing water retention, natural farming replaces synthetic inputs with biological self-regulation.Natural farming is an ecological approach to agriculture that emphasizes soil health, biodiversity, recycling of farm resources and reduced dependence on external chemical inputs. Its effect on crop yield depends on crop type, soil, climate, management quality and the duration of

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adoption.Therefore, successful natural farming requires proper planning, scientific nutrient management, suitable crop selection, efficient water management and effective pest and weed management. Rather than judging natural farming only by its immediate yield, its effects on production costs, soil health, resource conservation and long-term yield stability should also be considered.

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Potential Plant Extracts for Natural Farming Crop Protection

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Introduction

Natural farming aims to maintain crop health with minimum dependence on synthetic pesticides and fertilizers. Plant-based extracts are important components of ecological crop protection because many plants contain naturally occurring compounds that can repel insects, reduce feeding, inhibit microbial growth, or disturb the development of pests. When properly prepared and applied, these extracts can be used as part of an Integrated Pest Management (IPM) approach.

2. Meaning of Plant Extracts

A plant extract is a preparation obtained by collecting useful compounds from leaves, seeds, bark, roots, flowers, fruits, or other plant parts using water, fermentation, or other suitable extraction methods. In natural farming, simple water-based or fermented preparations are commonly preferred because they are inexpensive and can often be prepared locally.

3. Why Plant Extracts Are Useful

They provide a low-cost option for managing many common crop pests.

Several extracts have insect-repellent, antifeedant, ovicidal, or growth-regulating effects.

They can support biodiversity and reduce unnecessary dependence on broad-spectrum synthetic pesticides.

Locally available plants can be used, making the approach suitable for small and marginal farms.

Plant extracts can be incorporated with other natural practices such as sanitation, resistant varieties, traps, biological control, and proper irrigation.

4. Important Precaution

Plant extracts are not automatically harmless. Their strength varies with plant species, plant part, maturity, extraction method, concentration, and storage. A small test on a few plants should be conducted before field-wide application. The recommended label or local agricultural guidance should always be followed, particularly for food crops.

5. General Principle of Action

Plant-derived compounds may act through several mechanisms. Some repel insects by their smell or taste; others interfere with feeding, egg laying, moulting, or larval development. Certain extracts also show antimicrobial activity against selected plant pathogens. Their effect is often preventive or suppressive rather than a complete eradication of pests.

Potential Plant Extracts – Major Examples

1. Neem (Azadirachta indica)

Neem is one of the best-known botanical materials used in crop protection. Neem seeds and leaves contain biologically active compounds, including azadirachtin in neem seed material. Neem-based preparations may act mainly as antifeedants, repellents and insect growth regulators, and are used against several insect pests.

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2. Garlic (Allium sativum)

Garlic contains sulfur-containing compounds responsible for its characteristic smell. Garlic extracts are commonly used as repellents and may help suppress some soft-bodied insects and other pests. They are often combined with chilli or soap-based preparations in traditional crop protection systems.

3. Chilli (Capsicum spp.)

Chilli contains capsaicinoids, particularly capsaicin, which produces its pungency. Chilli-based extracts are traditionally used as insect repellents and antifeedants. Because concentrated chilli preparations can irritate skin and eyes, safe handling and dilution are important.

4. Tobacco (Nicotiana tabacum)

Tobacco leaves contain nicotine, a potent natural insecticide. However, nicotine is highly toxic to humans and non-target organisms and is hazardous to handle. Tobacco-based preparations therefore require special caution and should not be recommended for routine home preparation. Use only where legally permitted and under appropriate agricultural guidance.

5. Pongamia / Karanja (Pongamia pinnata)

Karanja seeds contain bioactive compounds and oil that have been used traditionally in botanical pest-management preparations. Karanja-based products may have repellent and insecticidal properties and are available commercially in some agricultural systems.

6. Custard Apple (Annona squamosa)

Seeds of custard apple contain compounds with insecticidal activity. Extracts have been investigated for effects on insect feeding and development. Because seed extracts can be biologically active, correct concentration and careful handling are essential.

7. Other Plants of Interest

Lantana – traditionally investigated for insect-repellent and insecticidal activity.

Eucalyptus – aromatic leaf compounds may provide repellent effects.

Calotropis – latex and plant extracts have bioactive properties but can be irritating or toxic.

Tulsi (Ocimum spp.) – aromatic compounds may contribute to repellent activity.

Ginger – extracts are traditionally explored as part of botanical pest-management mixtures.

8. Summary Table

Plant	Common use	Important note
Neem	Repellent, antifeedant, growth regulation	Widely used botanical option
Garlic	Repellent / pest suppression	Strong odor; test for crop injury
Chilli	Repellent / antifeedant	Irritant; handle carefully
Karanja	Botanical pest management	Use standardized preparations where possible

Preparation, Application And Safety

1. General Preparation Methods

Plant materials can be prepared as fresh extracts, infusions, decoctions, fermented extracts, or commercially formulated botanical products. The appropriate method depends on the plant material and the target pest. For routine farm use, clean water, clean containers, correct identification of the plant, and careful filtering are important.

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2. Simple Water-Based Extract

Select healthy plant material and remove soil and damaged portions.

Wash the material and chop or crush it to increase the surface area.

Soak or macerate the material in clean water for an appropriate period.

Filter the preparation through a fine cloth to prevent clogging of the sprayer.

Dilute according to a tested or officially recommended formulation before application.

Prepare fresh whenever possible and keep the preparation away from direct sunlight.

3. Fermented Plant Extract

Fermented extracts are prepared by allowing suitable plant materials to undergo controlled fermentation in water. Fermentation can alter the chemical composition and may improve extraction of certain compounds. However, fermentation time, temperature, plant material, and hygiene affect the final product, so a standard recipe and local technical guidance should be followed.

4. Application

Apply during the cooler part of the day, avoiding intense midday heat.

Ensure good coverage of the plant surface, especially the underside of leaves when appropriate.

Use clean spraying equipment and filter extracts carefully.

Avoid spraying when strong rain is expected because the material may be washed off.

Repeat applications only when monitoring shows continued pest pressure and when the formulation is suitable for repeated use.

Rotate management methods rather than relying on one extract continuously.

5. Safety Measures

Wear gloves, protective clothing, and eye protection when preparing or spraying concentrated extracts.

Do not taste, inhale, or directly contact concentrated plant preparations.

Keep preparations away from children, animals, food, drinking water, and feed.

Clearly label stored preparations with the plant name and date of preparation.

Do not mix different extracts or chemical pesticides unless compatibility and safety are established.

Test a small crop area first to check for phytotoxicity such as leaf burn, spotting, or wilting.

6. Environmental Considerations

Botanical pesticides can affect beneficial insects and other non-target organisms, particularly when concentrated or applied indiscriminately. Spray only when necessary, avoid flowering periods when pollinators are actively foraging where possible, and prefer targeted applications. Natural farming works best when plant extracts are one component of a broader ecological management system.

Integrated Natural Crop Protection

1. Role in Integrated Pest Management

Plant extracts should be used as one part of Integrated Pest Management rather than as a single solution. Regular field observation helps identify the pest, its life stage, and the level of crop damage. Management should begin with preventive and cultural practices, followed by mechanical, biological, and botanical measures when required.

2. Recommended Natural Farming Strategy

Use healthy seeds and suitable crop varieties.

Maintain field sanitation and remove severely infected plant material where appropriate.

Maintain proper spacing, irrigation, drainage, and balanced plant nutrition.

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Encourage natural enemies such as predators and parasitoids by conserving suitable habitat.

Use traps, physical barriers, hand collection, or other mechanical measures where practical.

Apply a suitable botanical extract only after identifying the pest and confirming the need for treatment.

Monitor the crop after treatment and record the result for future decisions.

3. Advantages

Potentially lower dependence on synthetic pesticides.

Many source plants are locally available and renewable.

Can fit small-scale and resource-conserving farming systems.

Some botanical compounds have multiple modes of action.

Useful as a component of resistance-management and IPM programs when used appropriately.

4. Limitations

Effectiveness can be variable because plant extracts are not always standardized.

Some preparations degrade rapidly during storage.

Incorrect concentration may cause crop injury.

Botanical extracts may be less effective under severe pest infestation than a properly selected registered pesticide.

Some plants contain highly toxic compounds and should not be used casually.

Legal requirements, residue standards, and crop-specific recommendations must be considered for commercial food production.

5. Conclusion

Potential plant extracts offer an important group of tools for natural and ecological crop protection. Neem, garlic, chilli, karanja, and selected other plants contain bioactive compounds that may repel pests, reduce feeding, or interfere with insect development. Their greatest value is achieved when they are prepared carefully, used at appropriate concentrations, and integrated with cultural, mechanical, and biological practices. Natural farming should focus on prevention, regular monitoring, biodiversity, and safe, need-based crop protection rather than indiscriminate spraying.

6. Key Points for Examination

Plant extracts are botanical preparations obtained from biologically active plant parts.

Neem is a major example of a botanical crop-protection material.

Botanical extracts may act as repellents, antifeedants, insect growth regulators, or antimicrobial agents.

Correct identification, preparation, dilution, and application are essential.

Always consider crop safety, beneficial organisms, human safety, and applicable regulations.

Integrated use with other natural farming practices gives more reliable crop protection.

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Remote Sensing For Crop Growth Monitoring

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Introduction

Agriculture depends on timely information about crop condition, plant growth, soil moisture and environmental stress. Traditional field observation is useful but can be time-consuming and may cover only a small part of a large farm. Remote sensing provides a way to collect information about crops over large areas without physically visiting every field.

Remote sensing is the science of obtaining information about an object or area from a distance, mainly by measuring reflected or emitted electromagnetic radiation. In agriculture, sensors mounted on satellites, aircraft or drones record information from crop canopies. The collected data can then be processed to understand crop growth, identify stress and support farm management decisions.

2. Meaning of Crop Growth Monitoring

Crop growth monitoring means observing and assessing the development of a crop from sowing to harvest. Important characteristics include germination, plant density, leaf area, canopy development, biomass, crop vigour, water status, nutrient condition and maturity. Regular monitoring helps identify abnormal areas early so that suitable management actions can be considered.

3. Role of Remote Sensing in Agriculture

Remote sensing allows repeated observation of agricultural fields at different stages of crop growth. A sequence of images collected over time can show changes in vegetation cover and crop condition. This is particularly useful for large farms and regions where frequent field visits are difficult.

The basic principle is that healthy vegetation interacts with sunlight differently from bare soil, water and stressed vegetation. Leaves generally absorb much of the visible red light for photosynthesis and reflect a relatively large amount of near-infrared radiation. Sensors measure these differences and convert them into digital data that can be mapped and analysed.

4. Objectives of Crop Growth Monitoring Using Remote Sensing

• To observe crop development at different growth stages.

• To estimate vegetation cover, crop vigour and biomass-related characteristics.

• To detect water, nutrient and other forms of crop stress at an early stage.

• To identify spatial differences within a field.

• To support irrigation, fertilizer and other farm-management decisions.

• To provide timely information for crop forecasting and agricultural planning.

5. Remote Sensing Platforms and Sensors

Different platforms can be used for crop monitoring. Satellites are useful for monitoring large regions and provide repeated images over time. Drones can capture very high-resolution images of individual farms and are useful for detailed field-level observations. Aircraft can also carry sensors for regional surveys.

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Sensors may record information in different portions of the electromagnetic spectrum. Multispectral sensors commonly collect data in several broad bands such as blue, green, red and near-infrared. Hyperspectral sensors collect information in many narrow spectral bands and can provide more detailed information about plant properties. Thermal sensors can help study surface temperature and water stress.

6. Important Spectral Information for Crop Monitoring

Visible wavelengths are associated with the colours perceived by the human eye. Chlorophyll strongly absorbs red light, while healthy green leaves tend to reflect more green and near-infrared radiation. Near-infrared response is strongly related to leaf and canopy structure. Changes in these spectral responses can therefore indicate differences in vegetation condition.

7. Vegetation Indices

Vegetation indices are mathematical combinations of spectral bands used to highlight vegetation characteristics. They are widely used to compare crop condition across fields and dates.

NDVI – Normalized Difference Vegetation Index

NDVI is one of the most widely used indices for vegetation monitoring. It is calculated from near-infrared (NIR) and red (Red) reflectance as:

$$NDVI = (NIR - Red) / (NIR + Red)$$

Higher NDVI values generally indicate greater green vegetation activity, while lower values may indicate sparse vegetation, bare soil or stressed crops. NDVI should not be treated as a direct measurement of yield because its interpretation is affected by crop type, growth stage, soil background, atmospheric conditions and sensor characteristics.

Other Useful Indices

Enhanced Vegetation Index (EVI) can improve vegetation monitoring in areas with dense vegetation and reduce some atmospheric and soil background effects. Normalized Difference Water Index (NDWI) and related water-sensitive indices can help assess vegetation or surface water conditions. Red-edge indices are particularly useful with sensors that have red-edge spectral bands and can provide information related to chlorophyll and crop stress.

8. Procedure for Crop Growth Monitoring

Step 1 – Define the monitoring objective

First, the purpose of monitoring is identified. It may be to map crop area, assess crop vigour, detect stress, estimate biomass, monitor irrigation or support yield assessment.

Step 2 – Collect remote sensing data

Suitable satellite, drone or aerial images are selected according to the crop, field size, required spatial resolution and monitoring frequency. Images from several dates are especially useful for studying crop growth over time.

Step 3 – Pre-process the images

Raw imagery may require corrections and preparation before analysis. Common steps include geometric correction, atmospheric correction, cloud masking, image mosaicking and clipping the data to the study area.

Step 4 – Calculate vegetation indicators

Vegetation indices such as NDVI can be calculated from appropriate spectral bands. The resulting values can be displayed as maps to show differences in vegetation condition within the field.

Step 5 – Compare images over time

Images from different dates can be compared to identify increasing or decreasing vegetation activity. A healthy crop normally shows a characteristic seasonal pattern from early growth through canopy development, maturity and senescence.

Step 6 – Identify crop stress

Areas with unusual spectral responses can be investigated for possible causes such as inadequate

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water, nutrient deficiency, pest or disease damage, flooding, salinity or physical crop damage. Remote sensing indicates where a problem may exist; field inspection is often needed to confirm the actual cause.

Step 7 – Ground verification

Field observations, photographs, crop measurements and farmer information can be used to verify remote sensing results. This process, called ground truthing or ground verification, improves the reliability of interpretation.

9. Applications

• **Crop vigour assessment:** Mapping differences in vegetation condition across fields.

• **Irrigation management:** Identifying areas that may require closer inspection for water stress.

• **Nutrient management:** Detecting spatial patterns that may be associated with nutrient problems.

• **Pest and disease monitoring:** Locating unusual crop patches for field inspection.

• **Crop acreage mapping:** Identifying and estimating areas under different crops

• **Yield assessment:** Using crop condition and seasonal observations as inputs to yield estimation models.

• **Disaster assessment:** Mapping crop damage caused by floods, drought, storms and other events.

10. Advantages of Remote Sensing for Crop Monitoring

• Covers large agricultural areas quickly.

• Provides repeated observations throughout the crop season.

• Can reveal spatial variability that may not be obvious from limited field observations.

• Supports timely identification of areas needing field inspection.

• Provides digital maps that can be integrated with GIS and other agricultural datasets.

• Can reduce the time and effort required for some types of field surveys.

11. Limitations

• Cloud cover can prevent the use of optical satellite images on some dates.

• Different crops and growth stages can produce similar spectral responses, making interpretation difficult.

• Remote sensing usually identifies patterns or possible stress rather than directly identifying the exact cause.

• High-resolution drone or commercial imagery may require additional equipment, skills or cost.

• Atmospheric effects, soil background and sensor differences can influence measurements.

• Ground verification is important when accurate crop diagnosis is required.

12. Future Scope

The use of remote sensing in agriculture is expanding with improved satellite constellations, drones, artificial intelligence, machine learning and cloud-based image processing. Combining remote sensing with weather data, soil information, field sensors and farm records can improve crop monitoring and support precision agriculture. Near-real-time monitoring may help farmers and agricultural agencies respond more quickly to crop stress and environmental changes.

13. Conclusion

Remote sensing is an important technology for modern crop growth monitoring. It provides repeated, spatially detailed information about vegetation condition and helps identify changes during the crop season. Vegetation indices such as NDVI are useful tools for assessing crop vigour, while thermal and other spectral information can add

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evidence about water and plant stress. When remote sensing results are combined with field observations, GIS, weather and soil data, they can support better crop management, resource use and agricultural planning.

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Intercropping For Suitable Crop Production

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Introduction

Agriculture is an important source of food, raw materials and employment. To increase production from limited land and resources, farmers follow improved crop production practices. One important practice is **intercropping**. It means growing two or more crops together in the same field during the same growing season. Suitable crops are selected so that sunlight, water, nutrients and space are used efficiently.

2. Definition of Intercropping

Intercropping is the practice of growing two or more crops simultaneously on the same piece of land during a particular growing season. Crops are selected based on growth duration, plant height, root system, nutrient requirements and water requirements. Examples include maize + cowpea, maize + black gram, sorghum + red gram, groundnut + red gram and cotton + black gram.

3. Objectives of Intercropping

The major objectives of intercropping are:

- Increase total crop production per unit area.
- Efficiently use land, water and nutrients.
- Reduce the risk of complete crop failure.
- Suppress weed growth.
- Improve soil fertility.
- Reduce certain pest and disease problems.
- Provide additional income to farmers.
- Improve stability of farm production.
- Utilize sunlight efficiently.
- Promote sustainable agriculture.

4. Types of Intercropping

Mixed intercropping: Two or more crops are grown together without a definite row arrangement. Example: sorghum + red gram.

Row intercropping: Crops are grown in definite rows. Example: maize + cowpea.

Strip intercropping: Crops are grown in strips wide enough for separate cultivation but close enough to interact. Example: maize + soybean.

Multi-storey intercropping: Crops of different heights occupy different vertical layers. Example: coconut + black pepper + pineapple

5. Intercropping for Suitable Crop Production

Proper crop selection is essential for successful intercropping. Component crops should have complementary characteristics so that competition is reduced.

Selection of Suitable Crops: Crops with different growth habits, root systems and nutrient requirements should be selected. Example: tall maize with short-duration cowpea.

Selection Based on Duration: A long-duration crop can be combined with a short-duration crop, allowing the short-duration crop to be harvested earlier. Example: red gram + black gram.

Selection Based on Plant Height: Tall and short crops can be combined to utilize sunlight at different levels. Example: maize + cowpea.

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Selection Based on Root System: Crops with different rooting depths can use water and nutrients from different soil layers.

Legume-Based Intercropping: Legumes such as black gram, green gram, cowpea and red gram can be combined with cereals. They contribute nitrogen through biological nitrogen fixation.

6. Advantages of Intercropping

Intercropping has several important advantages in crop production.

Higher Productivity: Suitable combinations can produce more total output from the same land.

Efficient Use of Resources: Different crops use sunlight, water, nutrients and space differently.

Weed Suppression: Greater crop cover reduces light reaching weeds and can suppress weed growth.

Pest Management: Crop mixtures can make it more difficult for some pests to locate their preferred host.

Disease Management: Crop diversity can reduce continuous spread of some crop-specific diseases.

Soil Fertility Improvement: Legume intercrops contribute nitrogen through biological nitrogen fixation, and residues add organic matter.

Risk Reduction: If one crop is affected by unfavorable conditions, the other may still provide yield.

Additional Income: More than one crop can provide food or income from the same field.

7. Role of Intercropping in Crop Protection

Pest management: Different plant species can disturb pest movement and host-finding. Some intercrops can attract predators and parasitoids.

Disease management: Crop diversity can reduce continuous spread of certain diseases when intercrops are not hosts of the same pathogens.

Weed management: Dense crop cover and competition for light, water and nutrients can suppress weeds. **Beneficial insects:** Flowering intercrops can provide nectar, pollen and shelter to beneficial insects. Intercropping can therefore be used as one component of **Integrated Pest Management (IPM)**

8. Examples of Suitable Intercropping Systems

The following combinations are commonly used examples:

Main Crop	Intercrop	Major Benefit
Maize	Cowpea	Resource use and
Maize	Black gram	Additional legume
Sorghum	Red gram	Efficient land use
Groundnut	Red gram	Additional
Cotton	Black gram	Ground cover and
Sugarcane	Green gram	Additional short-
Coconut	Black	Better vertical

9. Limitations of Intercropping

Although intercropping has many benefits, it also has some limitations. • Competition may occur for water, nutrients and sunlight.

• Mechanized operations can be difficult in some systems.

• Proper crop combination and spacing are required.

• Harvesting may be more difficult than in a sole crop.

• Poorly selected crops may reduce main-crop yield.

• Management is more complex.

• Different crops may require different fertilizer and plant-protection practices.

10. Principles for Successful Intercropping

The following principles should be considered for successful intercropping: • Select compatible crops.

• Choose crops with different growth durations.

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• Select crops with different plant heights and root systems.

• Maintain suitable row spacing.

• Avoid excessive competition.

• Use suitable fertilizer and irrigation practices.

• Select crops according to soil and climate.

• Follow proper weed and pest management.

• Use quality seeds.

• Consider local market demand

11. Conclusion

Intercropping is an important crop production practice in which two or more crops are grown together in the same field during the same season. Properly designed systems can improve the use of land, water, nutrients and sunlight. They can also suppress weeds, reduce certain pest and disease problems, improve soil fertility and provide additional income.

The success of intercropping depends on proper crop selection, planting arrangement, spacing, duration and management. Cereal–legume combinations such as **maize + cowpea, sorghum + red gram and maize + black gram** are common examples.

Thus, intercropping is a useful practice for **sustainable, productive and risk-reducing crop production.**

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Critical Period of Weed Competition in Major Crops

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Introduction

Weeds are unwanted plants that grow along with crops and compete with them for water, nutrients, sunlight, space and carbon dioxide. Weed competition is one of the major factors responsible for reduction in crop growth and yield. The effect of weeds is particularly severe during the early stages of crop growth, when crop plants are small and unable to compete effectively with weeds.

The critical period of weed competition is the period during the crop growth cycle when weeds must be controlled to prevent significant yield loss. Weed control during this period is more important than keeping the field completely weed-free throughout the entire crop season. The critical period varies with crop species, variety, weed species, weed density, soil fertility, climate, planting method and available moisture.

Meaning of Critical Period of Weed Competition

The critical period of weed competition is the period in the crop's life cycle during which the presence of weeds causes maximum reduction in crop yield. If weeds are effectively controlled during this period, the crop can generally tolerate weeds during the remaining part of its growth with comparatively less effect on yield.

In simple terms, the critical period is the most important period during which weeds should be controlled to protect crop yield. Usually, this period occurs during the early vegetative and early reproductive stages of the crop.

Importance of Critical Period

Knowledge of the critical period helps farmers to identify the correct time for weed control, reduce unnecessary expenditure on herbicides and labour, prevent major yield losses, improve crop growth and development, make efficient use of water and fertilizers, and improve the efficiency of integrated weed management.

Weed control before the critical period may sometimes be unnecessary, while weed control after the critical period may not recover the yield already lost. Therefore, timely weed management is essential.

Rice

Critical period: generally 15–45 days after transplanting in transplanted rice; in direct-seeded rice, approximately 15–45 days after sowing depending on the production system.

Major weeds include Echinochloa crus-galli, Echinochloa colona, Cyperus iria, Cyperus difformis, Monochoria species and Eclipta species. Weeds compete with rice for nutrients, water and sunlight. Heavy infestation during early stages can result in poor tillering and reduced grain yield. Management includes hand weeding, mechanical weeding, proper water management, suitable herbicides and integrated weed management.

Wheat

Critical period: approximately 15–35 days after sowing.

Major weeds include Phalaris minor, Avena ludoviciana, Chenopodium album, Rumex species

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and Melilotus species. Weeds compete strongly with wheat for nitrogen, moisture and sunlight. If weeds remain uncontrolled during early growth, plant population and tillering may be reduced. Timely sowing, proper seed rate, competitive varieties, recommended herbicides and mechanical or hand weeding can help.

Maize

Critical period: approximately 15–45 days after sowing.

Major weeds include Echinochloa colona, Cynodon dactylon, Cyperus rotundus, Amaranthus species and Trianthema portulacastrum. Severe early weed competition can reduce plant growth and grain yield. Inter-cultivation, hand weeding, mulching and suitable pre- and post-emergence herbicides are useful.

Groundnut

Critical period: generally 15–45 days after sowing.

Major weeds include Cyperus rotundus, Echinochloa species, Digitaria species, Trianthema portulacastrum and Amaranthus species. Early weed competition reduces plant growth and can interfere with pegging and pod development. Inter-cultivation, hand weeding and suitable herbicides are commonly used.

Cotton

Critical period: approximately 15–60 days after sowing.

Major weeds include Cyperus rotundus, Cynodon dactylon, Trianthema portulacastrum, Amaranthus species and Parthenium hysterophorus. Weeds compete for nutrients, water and sunlight. Inter-cultivation, hand weeding, mulching, suitable herbicides and proper crop spacing are useful management practices.

Soybean

Critical period: generally 15–45 days after sowing.

Major weeds include Echinochloa colona, Cyperus rotundus, Amaranthus species, Commelina benghalensis and Parthenium hysterophorus. Weeds reduce growth, branching and pod formation. Timely sowing, proper spacing, inter-cultivation, hand weeding and recommended herbicides can be used.

Sugarcane

Critical period: approximately 30–120 days after planting.

Major weeds include Cynodon dactylon, Cyperus rotundus, Echinochloa species, Saccharum spontaneum and Parthenium hysterophorus. Weeds compete for water, nutrients and sunlight and can reduce tiller production and cane yield. Inter-row cultivation, earthing up, mulching, hand weeding and suitable herbicides are useful.

Pulses

Critical period: in many pulse crops, approximately 15–45 days after sowing, although it varies with crop and environment.

Blackgram, greengram, pigeonpea and chickpea can be affected by weeds during early growth. Major weeds include Cyperus species, Echinochloa species, Amaranthus species, Trianthema species and Parthenium species. Timely intercultivation, hand weeding, mulching, suitable herbicides and maintaining proper plant population are useful.

Potato

Critical period: approximately 20–50 days after planting.

Major weeds include Chenopodium album, Cyperus rotundus, Amaranthus species and Cynodon dactylon. Weeds reduce nutrient and water availability and may interfere with tuber development. Earthing up, inter-row cultivation, hand weeding, mulching and appropriate herbicide use can help.

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Summary of Critical Periods

Rice – 15–45 days after transplanting/sowing
Wheat – 15–35 days after sowing
Maize – 15–45 days after sowing
Groundnut – 15–45 days after sowing
Cotton – 15–60 days after sowing
Soybean – 15–45 days after sowing
Sugarcane – 30–120 days after planting
Pulses – 15–45 days after sowing
Potato – 20–50 days after planting

These periods are approximate and can vary with crop variety, weed flora, climate, soil and management practices.

Factors Affecting the Critical Period

The critical period is influenced by crop species, weed species, weed density, soil fertility, moisture availability, climate, crop geometry and the time of weed emergence. Weeds emerging at the same time as the crop generally cause greater competition than weeds emerging later.

Weed Management During the Critical Period

Effective weed management should concentrate on the critical period rather than relying on continuous weed removal. Cultural methods include clean seed, optimum plant population, proper spacing, competitive varieties, timely sowing and crop rotation. Mechanical methods include hand weeding, hoeing, inter-cultivation and earthing up. Chemical methods include suitable pre-emergence and post-emergence herbicides used according to crop and weed conditions. Integrated weed management combines suitable cultural, mechanical, chemical and biological methods.

Conclusion

The critical period of weed competition is an important concept in crop production. Weeds are most harmful when they compete with crops during sensitive stages of growth. In many major crops, this period occurs mainly during the early growth stage, although the exact duration differs between crops.

Timely weed control during the critical period helps the crop obtain sufficient water, nutrients, sunlight and space, resulting in better growth and higher yield. Therefore, identifying the critical period and adopting suitable integrated weed management practices are essential for economical and sustainable crop production.

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Agronomic Management of *Stylosanthes* Under Water-Limited Conditions

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ABSTRACT

To provide a complete, field-tested agronomic framework and physiological management guide for maximizing biomass yield, seedling persistence, nutritional value, and disease resistance in Stylosanthes (Stylo) pasture systems under water-scarce, dryland, and drought-prone tropical or subtropical environments.

1.Introduction & Botanical Overview

Stylosanthes (commonly referred to as **Stylo**) is a genus of high-value tropical and subtropical pasture legumes belonging to the family Fabaceae. Native to Central and South America, Stylo has become an essential forage component across tropical Asia, Africa, and Australia due to its outstanding adaptability to acidic, low-fertility soils and harsh dry seasons.

As a deep-rooted perennial or short-lived perennial herb, Stylo plays an indispensable role in livestock production systems. It delivers high crude protein (12–18%), enhances soil structure, fixes atmospheric nitrogen (50–150 kg N/ha/year), and prevents soil degradation in fragile dryland ecosystems.

Physiological Responses to Water Deficits

Under prolonged soil moisture deficit, *Stylosanthes* exhibits coordinated physiological defenses to prevent desiccation. Early responses include reduced leaf expansion rates and rapid stomatal closure driven by abscisic acid (ABA) signaling from root tips. While stomatal closure conserves internal moisture, it restricts internal CO2 concentrations, lowering photosynthetic rates and biomass accumulation.

Additionally, extreme drought impairs root nodulation by suppressing infection thread development by *Bradyrhizobium* bacteria, thereby temporarily halting biological nitrogen fixation. Prolonged moisture stress leads to leaf senescence, canopy dieback, and reduced carbohydrate reserves in stem bases.

2.Species & Cultivar Selection

Selecting the appropriate *Stylosanthes* species and cultivar tailored to regional rainfall patterns, soil textures, and temperature regimes is the foundational step in mitigating drought risk.

Species / Cultivar	Annual Rainfall	Growth Habit	Key Agronomic Attributes & Stress Adaptation
S. scabra (cv. 'Seca')	400 – 900 mm	Erect, woody shrub (up to 2m)	Possesses a deep woody taproot penetrating over 2 meters. Highly persistent under extreme semi-arid dry spells.
S. hamata (cv. 'Verano')	500 – 1000 mm	Prostrate to semi-erect herb	

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High seed producer; rapid post-rain germination; excellent for short-term pastures and intercropping.

S. guianensis
(cv. 'Cook', 'Graham')

700 – 1200+ mm

Erect to sub-erect perennial

High green biomass yield; highly palatable; suitable for subhumid regions with brief dry seasons.

S. capitata
(cv. 'Campo Grande')

600 – 1100 mm

Semi-erect herbaceous legume

Exceptional resistance to Anthracnose disease and adapted to highly acidic, infertile dryland soils.

3.LAND PREPARATION & SOIL MOISTURE HARVESTING

In dryland farming systems, land preparation must prioritize maximum moisture retention and minimize surface runoff during sporadic rain events.

- **Conservation Tillage & Zero-Till:** Deep tillage exposes subsoil to direct heat, accelerating evaporation. Utilizing zero-till or minimum tillage preserves topsoil organic matter, maintains soil aggregate stability, and retains residual soil moisture.
- **In-Situ Water Harvesting Systems:** Constructing contour bunds, broad-bed and furrow (BBF) systems, or micro-catchment ridges directs surface runoff into root zones during heavy downpours.
- **Organic Surface Mulching:** Applying 3–5 tonnes/ha of crop residues (e.g., maize stalks or straw) shades the soil surface.

Mulching lowers soil surface temperatures by 3–5°C and reduces moisture evaporation by 15–25%.

4.Seed Treatment & Establishment

Successful seedling establishment during short initial rain windows is critical for developing deep roots before the dry season begins.

- **Scarification & Hardening:** Stylo seeds exhibit high hard-seededness (>70%). Soaking seeds in hot water (80°C) for 2–3 minutes breaks coat dormancy. Pre-soaking in 1% KH_2PO_4 or 1% KCl for 4–6 hours improves cellular osmotic resilience during early emergence.
- **Precision Seeding:** Sow shallowly (0.5–1.0 cm) into a firm, moist seedbed. Recommended seeding rate is 3–5 kg/ha. Avoid higher seeding densities under dryland conditions to reduce competition for soil water.
- **Rhizobial Inoculation:** Inoculate seeds with specialized strains of *Bradyrhizobium* (e.g., strain CB756) to ensure effective root nodulation even in dry, nutrient-poor soils.

5.Nutrient Management & Physiological Stress Mitigation

Targeted plant nutrition boosts root elongation and optimizes stomatal control under limited moisture conditions.

5.1Phosphorus Optimization

Although Stylo is efficient at extracting soil phosphorus via vesicular-arbuscular mycorrhizal (VAM) associations, applying basal phosphorus (10–20 kg P_2O_5/ha) as Single Super Phosphate (SSP) at planting stimulates rapid primary root development and deep taproot penetration into subsoil moisture layers.

5.2Potassium & Micronutrient Foliar Sprays

Potassium (K^+) regulates cell turgor pressure and guards against excessive transpiration. Foliar application of 0.5–1.0% KCl during early drought

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onset enhances stomatal closure efficiency and reduces cellular electrolyte leakage.

6.Disease & Pest Management Under Moisture Stress

Drought-stressed plants are increasingly vulnerable to opportunistic diseases and pest infestations.

6.1 Anthracnose Control (*Colletotrichum gloeosporioides*)

Anthracnose is the most devastating fungal disease affecting *Stylosanthes* worldwide. Water-stressed plants experience rapid foliar necrosis upon rain resumption if fungal spores are present.

8. **Integrated Control:** Sow multi-line mixtures or resistant cultivars like 'Seca' and 'Campo Grande'. Treat seeds with Carbendazim or Mancozeb (2 g/kg seed) prior to planting.
9. **Canopy Management:** Avoid high planting densities to allow adequate airflow, lowering localized canopy humidity that triggers fungal germination.

7.Grazing & Canopy Management

Stylo regrowth relies heavily on growing points situated on stems rather than underground crowns. Defoliation management during dry spells determines stand longevity.

- **Stubble Height Control:** Never cut or graze below 15–20 cm. Retaining green stem bases preserves axillary buds required for post-drought shoot regeneration.
- **Rotational Grazing Cycles:** Implement rotational grazing schedules (1–2 weeks grazing followed by 4–8 weeks rest) to allow carbohydrate replenishment in stem bases.

8.Pasture Integration & Cropping Systems

Integrating Stylo into broader farming systems maximizes land productivity and water-use efficiency across seasons.

8.1Grass-Legume Mixed Pastures

Intercropping Stylo with drought-tolerant tussock grasses—such as *Cenchrus ciliaris* (Buffel grass) or *Urochloa mosambicensis* (Sabi grass)—creates a balanced forage system. The grass roots draw water from shallow soil layers while Stylo taproots tap subsoil reserves, minimizing root zone competition.

8.2Ley Farming & Green Manuring

In semi-arid cereal systems, growing Stylo as a 2–3 year pasture ley improves soil organic carbon, fixes residual nitrogen, and breaks hardpan layers, significantly boosting subsequent cereal crop yields.

9.Summary Agronomic Calendar For Dryland Stylo

Growth Stage	Agronomic Focus	Key Field Actions
Pre-Sowing (1–2 months pre-rains)	Moisture conservation & land prep	Construct contour bunds; apply organic mulch; procure scarified seed & rhizobium.
Sowing (At onset of rains)	Rapid germination & root depth	Treat seed with 1% KCl; sow at 0.5–1 cm depth; apply basal P fertilizer.
Establishment (30–60 days post-sowing)	Weed control & root growth	Hand weed inter-rows; monitor for anthracnose symptoms; avoid early grazing.
Mid-Season / Dry Spell	Osmoregulation & stand persistence	Apply foliar KCl spray (0.5%); enforce strictly 15–20 cm grazing stubble height.

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Post-Season / Harvest

Carbohydrate storage & seed set

Allow 6–8 weeks spell for seed drop and root reserve replenishment.

10.Conclusion

Achieving long-term sustainability and high biomass production from *Stylosanthes* under water-limited conditions requires a holistic, multi-faceted agronomic strategy. By matching drought-resistant cultivars (such as *S. scabra* cv. 'Seca') to local rainfall regimes, adopting conservation tillage, treating seeds for enhanced osmotic tolerance, applying strategic phosphorus fertilization, and maintaining conservative grazing stubble heights (>15 cm), pastoralists and farmers can build resilient forage systems capable of weathering severe climate variability.

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Natural Farming and Climate Changes: Current Situation and Rececnt Changes

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1.Introduction

Agriculture is closely connected with climate because crop growth, water availability, soil processes, pest and disease development, and farm productivity all depend on weather and environmental conditions. Climate change is increasing the frequency or intensity of heat stress, irregular rainfall, droughts, floods and other weather extremes in many agricultural regions. These changes create risks for food production, especially for small and rainfed farmers.

Natural farming is an agroecological approach that aims to reduce dependence on synthetic external inputs and strengthen the natural processes of the farm ecosystem. It commonly uses crop diversification, soil cover, biological inputs prepared from locally available resources, livestock integration, mulching, recycling of biomass, and ecological pest management. In India, natural farming has gained institutional support through the National Mission on Natural Farming (NMNF), approved in November 2024.

2. Meaning and Principles of Natural Farming

Natural farming is a chemical-free, ecosystem-based approach in which farmers attempt to manage soil, water, plants, animals and beneficial organisms as an interconnected system. The approach emphasizes locally available resources, minimum soil disturbance, living soil, biomass recycling and biological processes.

a. Use of on-farm biological inputs such as Beejamrit, Jeevamrit and other locally prepared formulations.

b. Mulching and maintenance of soil cover to conserve moisture and protect soil organisms.

c. Crop diversification, intercropping and mixed cropping to improve ecological stability.

d. Integration of livestock, where suitable, to recycle nutrients and support farm-based inputs.

e. Use of traditional or locally adapted seed and planting materials where appropriate.

f. Biological and ecological approaches for pest and disease management.

g. Efficient use of water and conservation of soil organic matter.

3. Climate Change and Agriculture

Climate change affects agriculture through changes in temperature, rainfall patterns and the occurrence of extreme events. Higher temperatures can shorten crop duration and increase evapotranspiration and water demand. Unpredictable rainfall can cause both water shortage and waterlogging. Heatwaves, droughts, floods and intense rainfall can damage crops, erode soil and disrupt farm operations.

ICAR publications on climate-resilient agriculture identify extreme weather, elevated temperatures and unpredictable rainfall as major challenges to Indian agriculture. The effects differ by region, crop, soil type, irrigation availability and farming practice.

4. How Natural Farming Can Help Climate Resilience

Natural farming can contribute to climate resilience mainly by improving the condition of the farm ecosystem. Practices such as mulching, biomass

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recycling, crop diversification and improved soil biological activity can support soil structure and moisture retention.

Diversified farms may also spread production risk because different crops respond differently to heat, rainfall and pest pressure.

Natural farming should not be considered a single solution to climate change. Results can vary with crop, soil, climate, management skill, market access and the availability of biomass and livestock resources. Therefore, location-specific scientific evaluation and farmer training are important.

5. Current Situation of Natural Farming in India

India has recently expanded institutional support for natural farming. The Union Cabinet approved the National Mission on Natural Farming (NMNF) on 25 November 2024 with a total outlay of ₹2,481 crore. The mission promotes chemical-free farming, diversified cropping, livestock integration, soil health improvement, ecosystem restoration and reduced input costs.

Government information released in July 2026 reported that 18,893 natural farming clusters covering 10.32 lakh hectares and involving 20.93 lakh farmers were formed during financial year 2025–26. The same update reported 33,257 trained Krishi Sakhis/Community Resource Persons and 7,601 Bio-Input Resource Centres. More than

22.47 lakh farmers had registered under the Natural Farming Certification System, with more than 14.43 lakh farmers certified.

The mission also provides an output-based incentive of ₹4,000 per acre per year for two years, limited to one acre per farmer, to support adoption and associated activities. These figures show rapid institutional expansion, but the scale of enrolment should not be interpreted as proof that all farms have achieved the same agronomic or economic outcomes.

6. Recent Changes in Climate Conditions Relevant to Farming

a. Increasing heat stress: Higher temperatures can affect flowering, pollination, grain or fruit development and livestock comfort.

b. Irregular rainfall: Changes in the timing and distribution of rainfall can disturb sowing, crop establishment and harvesting.

c. More frequent water stress: Longer dry spells can increase irrigation requirements and reduce soil moisture.

d. Heavy rainfall and flooding: Intense rainfall can cause erosion, nutrient loss, waterlogging and crop damage.

e. Changing pest and disease patterns: Temperature and humidity changes can alter the distribution and seasonal activity of pests and pathogens.

f. Soil degradation risks: Erosion, loss of organic matter and declining soil structure can reduce the ability of soils to withstand climatic stress.

g. Greater production uncertainty: Weather variability can increase yield fluctuations and make farm planning more difficult.

7. Recent Government and Institutional Responses

Current agricultural policy increasingly combines natural farming with broader climate-resilient and resource-conserving approaches. These include organic and natural farming, micro-irrigation, crop diversification, conservation agriculture, agroforestry, integrated farming systems and scientific soil-health management.

The NMNF uses clusters, training institutions, Community Resource Persons and Bio-Input Resource Centres to provide field-level support. Certification systems are also being developed to improve recognition and market access for natural-farming produce.

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ICAR and agricultural universities are also emphasizing climate-resilient crop varieties, efficient nutrient management, water conservation and integrated approaches. Such measures are important because climate adaptation generally requires a combination of technologies and management practices rather than one farming method alone.

8. Major Benefits of Natural Farming Under Climate Change

a. Improved soil cover and biological activity can support soil health.

b. Mulching and organic matter management can help conserve soil moisture.

c. Crop diversification can improve ecological stability and spread production risk.

d. Reduced dependence on purchased synthetic inputs may lower exposure to some input-price shocks.

e. On-farm recycling of biomass and livestock resources can improve nutrient cycling.

f. Biological pest management can reduce dependence on chemical pesticides when appropriately implemented.

g. Better soil structure and ground cover can help reduce erosion during heavy rainfall.

h. Natural farming can contribute to more resource-efficient and environmentally responsible farming systems.

9. Challenges and Limitations

a. Natural farming is knowledge-intensive and requires training, observation and continuous field support.

b. Transitioning from conventional systems can involve a learning period and changes in farm management.

c. Availability of biomass, livestock resources and locally suitable inputs differs among farms.

d. Yield responses are not uniform across crops, locations and management systems.

e. Reliable markets, certification and consumer awareness are important for obtaining value from naturally produced crops.

f. Climate resilience requires additional measures such as drought-tolerant varieties, water harvesting, irrigation management and weather advisories.

g. Scientific field trials and long-term monitoring are needed to evaluate productivity, profitability, soil health and greenhouse-gas outcomes under different conditions.

10.Future Prospect

The future of natural farming in a changing climate depends on combining traditional knowledge with scientific research. Priority areas include location-specific natural farming packages, climate-resilient varieties, soil biological indicators, water conservation, digital weather advisories, farmer field demonstrations and improved market systems.

Research should compare natural farming with other sustainable farming systems using long-term measurements of yield, profitability, soil organic carbon, water use, biodiversity and greenhouse-gas emissions. This evidence can help farmers select combinations of practices that are suitable for their own climate, soil and market conditions.

11. Conclusion

Climate change is creating increasing pressure on agricultural production through heat, rainfall variability, drought, flooding and other environmental stresses. Natural farming provides a pathway for strengthening ecological processes, improving soil management and reducing dependence on some external inputs. In India, the National Mission on Natural Farming has expanded rapidly since its approval in 2024, with substantial increases in farmer enrolment, clusters and area covered reported during 2025–26.

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Natural farming should be promoted through evidence-based, location-specific approaches rather than as a universal practice for every farm. Combining natural farming principles with climate-resilient varieties, efficient irrigation, crop diversification, soil-health management, scientific advisories and strong markets can help build more resilient agricultural systems

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Effects of Natural Farming on Soil Microbial Activity

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1.Introduction

Soil is a living ecosystem containing bacteria, fungi, actinomycetes, algae, protozoa and many other organisms. These microorganisms perform essential functions such as decomposition of organic matter, nutrient cycling, formation of soil aggregates and support of plant growth.

Natural farming is an agricultural approach that gives greater importance to natural biological processes and reduces dependence on synthetic fertilizers and pesticides. It uses practices such as mulching, crop-residue recycling, crop diversification, green manuring and suitable biological inputs.

The condition of soil microorganisms is closely connected with soil fertility. When microbial activity is maintained, organic materials are decomposed efficiently and nutrients are continuously recycled. Therefore, natural farming can influence soil microbial activity and long-term soil health.

2. Soil Microbial Activity

Soil microbial activity refers to the biological processes performed by microorganisms in soil. They obtain energy from organic materials and carry out reactions important for plant nutrition and soil development.

- Bacteria – decomposition, nutrient transformation and nitrogen-related processes.
- Fungi – decomposition of complex organic materials and beneficial root associations.
- Actinomycetes – decomposition of resistant organic substances.
- Algae and cyanobacteria – soil biological processes and, in some cases, nitrogen fixation.
- Protozoa – participation in the soil microbial food web and nutrient release.

3. Effects of Natural Farming on Soil Microbial Activity

3.1 Increase in Beneficial Microorganisms

Natural farming provides organic materials that can serve as food and energy sources for soil microorganisms. Crop residues, green manure and suitable organic materials can support microbial growth when soil moisture and other conditions are favourable.

3.2 Improvement in Microbial Diversity

Crop rotation, intercropping, residue recycling and reduced chemical disturbance provide different sources of carbon and nutrients. This can support a wider range of microbial groups and improve biological stability.

3.3 Increased Decomposition of Organic Matter

Microorganisms break down leaves, roots, crop residues and other organic materials. During decomposition, complex substances become simpler compounds. Nutrients are released and soil organic matter is continuously transformed.

3.4 Improvement in Nutrient Cycling

Microorganisms are essential for the cycling of carbon, nitrogen, phosphorus and sulphur. They transform nutrients between different chemical forms and help maintain nutrient availability within the soil-plant system.

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3.5 Nitrogen Fixation

Certain microorganisms convert atmospheric nitrogen into forms useful to plants. Rhizobium forms associations with legume roots, while other microorganisms can fix nitrogen independently. Legume-based natural farming systems can support these processes.

3.6 Phosphorus Solubilization

Some beneficial microorganisms can release phosphorus from poorly soluble compounds in soil. This can increase phosphorus availability to plant roots and improve nutrient-use efficiency.

3.7 Improvement in Soil Structure

Fungal hyphae and microbial substances help bind soil particles together. Better aggregation can improve pore space, aeration, water infiltration and root growth.

3.8 Increase in Soil Organic Carbon

Mulching, crop-residue recycling and suitable organic materials increase carbon-containing material in soil. Organic carbon provides an important energy source for microorganisms and supports biological activity.

3.9 Support for Plant Growth

Some soil microorganisms promote plant growth by improving nutrient availability, supporting root development and producing growth-associated substances. Beneficial root microorganisms can improve nutrient uptake.

3.10 Suppression of Some Soil-Borne Pathogens

A diverse microbial community can compete with harmful microorganisms for nutrients and space. Some beneficial microbes can inhibit particular pathogens, contributing to biological disease suppression.

4. Natural Farming Practices Supporting Microbial Activity

- Mulching – protects the soil surface, conserves moisture and supplies organic material.
- Crop-residue recycling – returns carbon and nutrients to the soil.
- Green manuring – adds fresh plant biomass and can stimulate microbial activity.
- Crop rotation – changes root exudates and residue types and supports microbial diversity.
- Intercropping – increases plant diversity and provides varied habitats and carbon sources.
- Reduced soil disturbance – helps protect soil habitats and microbial networks.
- Suitable biological inputs – can encourage beneficial microorganisms when properly selected and applied.

5. Benefits to Soil Health

- Improved decomposition of organic matter.
- Better nutrient cycling and nutrient availability.
- Support for soil organic matter and biological fertility.
- Improved soil aggregation and physical condition.
- Greater microbial diversity under suitable management.
- Better conditions for root growth and nutrient uptake.
- Contribution to biological suppression of some soil-borne diseases.
- Support for long-term soil health and sustainable crop production.

6. Factors Affecting Soil Microbial Activity

Microbial activity is influenced by soil moisture, temperature, pH, organic carbon, nutrient

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availability, aeration, soil texture, crop type and root activity.

Microbial populations also change with season and crop growth stage. Therefore, the effect of a farming practice should be evaluated together with local soil conditions, climate and duration of management.

7. Importance for Sustainable Agriculture

Maintaining active soil microbial communities is important because microorganisms perform many functions related to nutrient supply, decomposition and soil structure. Natural farming focuses attention on these biological processes.

Natural farming practices should be adapted to local conditions. Organic materials and biological inputs need to be used appropriately, and soil testing can help identify nutrient limitations. Long-term field observations are useful for understanding changes in microbial communities and soil fertility.

8.Role of Soil Microorganisms in Natural Farming

Soil microorganisms play an important role in maintaining soil fertility and supporting crop growth. Natural farming encourages biological activity by providing organic materials and reducing excessive chemical disturbance. A healthy microbial community helps maintain a balanced soil ecosystem.

8.1.Decomposition of Organic Materials:

Microorganisms decompose crop residues, fallen leaves, roots and other organic materials. During this process, complex organic substances are converted into simpler forms. This helps return nutrients to the soil and increases the availability of nutrients for plants.

8.2.Nutrient Availability:

Beneficial microorganisms participate in the cycling of important nutrients such as nitrogen, phosphorus, sulphur and carbon. Some microorganisms convert nutrients into forms that can be more easily absorbed by plant roots. This supports efficient nutrient use by crops.

8.3.Formation of Soil Aggregates:

Microbial activity contributes to the formation and stability of soil aggregates. Fungal hyphae and microbial substances help bind soil particles together. Good soil aggregation improves aeration, water infiltration and root growth.

8.4Root–Microbe Interaction:

The area around plant roots, called the rhizosphere, contains many microorganisms. Root exudates provide food for microorganisms, while beneficial microbes can support root development and nutrient uptake. This interaction helps maintain healthy plant growth.

8.5Maintenance of Soil Biological Balance:

A diverse microbial population can contribute to biological balance in the soil. Different groups of microorganisms occupy different ecological roles. Competition among microorganisms may also help restrict the growth of some harmful organisms.

8.6.Effect of Organic Matter:

Organic matter is an important source of energy for soil microorganisms. Practices such as mulching, green manuring and crop-residue recycling increase the supply of organic materials. This can encourage microbial growth when suitable moisture, temperature and aeration conditions are available.

8.7.Long-Term Soil Health:

Continuous support of microbial activity can contribute to improved biological fertility and soil health. Natural farming therefore gives importance to practices that maintain organic matter, microbial diversity and biological processes in the soil.

9. Conclusion

Natural farming can create favourable conditions for soil microbial activity through organic matter

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addition, crop diversification, mulching, residue recycling and reduced chemical disturbance. Beneficial microorganisms support decomposition, nutrient cycling, soil aggregation and plant nutrient availability.

A biologically active soil is an important foundation for sustainable crop production. Protecting and encouraging soil microbial diversity can contribute to improved soil fertility and long-term soil health. The response varies with soil type, climate, crop, management practices and duration of farming.

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Role of Capacity Building in Natural Farming

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1.Introduction

Natural farming is a farming approach that emphasizes ecological processes, locally available resources, biodiversity, recycling of farm biomass and reduced dependence on externally purchased synthetic inputs. In India, natural farming is being promoted as a nature-based and knowledge-intensive approach that can support soil health, lower input dependence and strengthen climate resilience. The National Mission on Natural Farming (NMNF) specifically recognizes training, awareness, handholding and capacity building as important for helping farmers shift from chemical-based farming towards natural farming practices. (Ministry of Agriculture & Farmers Welfare, 2023; PIB, 2025).

Capacity building means developing the knowledge, practical skills, confidence, decision-making ability and organizational capacity of farmers and other agricultural stakeholders. In natural farming, it is not enough to simply tell farmers to stop using synthetic inputs. Farmers need to understand how soil organisms, biodiversity, crop diversity, mulching, natural bio-inputs, water management and ecological pest management work together. Continuous learning therefore becomes an essential part of successful adoption.

2. Meaning of Capacity Building in Natural Farming

Capacity building is a continuous process through which farmers acquire knowledge, skills, resources, confidence and the ability to solve problems. In natural farming, it includes technical training, field demonstrations, farmer-to-farmer learning, access to extension services, record keeping, group organization, market information and linkages with agricultural institutions.

The Food and Agriculture Organization (FAO) emphasizes Farmer Field Schools (FFS), where farmers learn by observing, experimenting and discussing problems in their own fields. This approach is particularly relevant to natural farming because many practices are location-specific and require practical understanding rather than only classroom instruction. (FAO, 2026).

3. Major Areas of Capacity Building

a) Knowledge development: Farmers are trained in the principles of natural farming, soil health, biodiversity, crop planning, recycling of biomass and ecological pest management.

b) Practical skills: Farmers learn to prepare and use farm-made inputs, seed treatments, botanical preparations, composting and mulching techniques through demonstrations and hands-on practice.

c) Soil and water management: Training helps farmers understand soil structure, organic matter, moisture conservation, nutrient cycling and the importance of protecting soil biological activity.

d) Pest and disease management: Farmers learn to monitor crops, recognize beneficial organisms and use preventive and ecological approaches instead of depending only on chemical pesticides.

e) Farm planning and decision-making: Capacity building helps farmers select practices according to local soil, climate, crops, labour availability and available farm resources.

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f) Enterprise and marketing skills: Farmers also need knowledge about grading, packaging, record keeping, certification, branding, value addition and market linkages for naturally grown produce.

4. Role of Training and Demonstration

Training is one of the most direct forms of capacity building. Classroom sessions can provide concepts, but field demonstrations help farmers understand how practices are actually performed. Demonstration farms can show crop diversity, mulching, natural input preparation, livestock integration and other practices under local conditions.

The Government of India has been establishing training activities under the NMNF. A 2025 government release reported that training at Centres of Natural Farming had been initiated and that thousands of Krishi Sakhis had been trained in soil health and natural farming. In 2026, NITI Aayog also reported the launch of Hindi and English training manuals intended to provide practical, region-relevant knowledge to farmers, extension officers and field-level functionaries. (PIB, 2025; PIB, 2026).

5. Farmer Field Schools and Experiential Learning

Farmer Field Schools provide an important model for capacity building. Farmers meet regularly during the crop season, observe their fields, compare practices and discuss results with facilitators and other farmers. Instead of receiving only one-way advice, farmers participate in experiments and make decisions based on field observations.

This method can increase confidence and local problem-solving ability. FAO describes Farmer Field Schools as hands-on group learning that helps farmers understand agro-ecosystems and adapt sustainable practices to their own context. FAO has also documented capacity-development work on community-based natural farming in Andhra Pradesh using training of facilitators and farmers through Farmer Field Schools. (FAO, 2019; FAO, India).

6. Farmer-to-Farmer Learning and Community Institutions

Farmers often trust practical experiences from other farmers because the information is demonstrated under real farming conditions. Experienced natural farmers can act as resource persons, demonstration farmers or community trainers. Farmer groups and self-help groups can organize input preparation, demonstrations, knowledge sharing and collective marketing.

Community institutions also improve the continuity of learning. When farmers work together, they can share labour, locally available materials, observations and experiences. Such collective capacity can help natural farming practices spread beyond individual demonstration plots.

7. Role of Extension Agencies, KVKs and Agricultural Universities

Agricultural extension agencies, Krishi Vigyan Kendras (KVKs), Agricultural Universities, research institutions and local departments can provide scientific guidance and field-level support. Their role includes training farmers, developing locally suitable packages of practices, conducting demonstrations, monitoring results and communicating research findings in simple language.

The NMNF operational approach also recognizes the role of KVKs in on-field training of Community Resource Persons, Krishi Sakhis and farmers at model demonstration farms, including locally relevant natural farming practices and preparation of natural inputs. This creates a link between scientific institutions and farmers. (PIB, 2025).

8. Capacity Building for Natural Input Preparation

Natural farming depends greatly on knowledge of locally available resources. Capacity building can teach farmers how to identify suitable biomass, maintain livestock where integrated systems are used, prepare farm-made bio-inputs, treat seeds,

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manage residues and store inputs safely. Practical training should emphasize correct preparation, timing, application and observation of crop response.

Such training can reduce dependence on purchased inputs when locally available resources are suitable. However, farmers should be encouraged to use evidence-based, locally appropriate practices and to seek technical advice when problems such as serious pest outbreaks or nutrient deficiencies occur.

9. Digital Tools and Knowledge Sharing

Mobile phones and digital communication can support capacity building by providing weather information, crop advisories, training videos, market information and access to experts. Digital tools should complement, rather than replace, field demonstrations because many natural farming practices require hands-on learning.

Training materials should be available in languages understood by local farmers and should use simple explanations, pictures and demonstrations. Inclusive training is especially important for women farmers, youth, tenant farmers and smallholders who may have limited access to formal extension services.

10. Economic and Social Benefits of Capacity Building

Capacity building can improve the ability of farmers to plan their farms, use local resources efficiently, identify problems early and make informed decisions. It can also strengthen farmer organizations and create opportunities for local enterprises related to natural inputs, processing, value addition and marketing.

FAO notes that farmer capacity develops through learning and practice and that community-based learning can improve agricultural management and livelihood-related skills. Therefore, capacity building should not be treated as a one-time training programme; it should be a continuing process involving learning, practice, feedback and improvement. (FAO, 2011).

11. Challenges in Capacity Building

Several challenges can limit the effectiveness of capacity building. These include lack of trained facilitators, differences in local agro-climatic conditions, limited access to demonstrations, language barriers, insufficient follow-up, lack of market information and uncertainty during the transition to new practices.

Another challenge is that farmers may receive information from many sources that differs in quality. Strong extension networks, scientifically informed training materials, field demonstrations and regular monitoring can help improve the reliability of information. Capacity building should also recognize farmers' existing traditional knowledge and combine it appropriately with scientific evidence.

12. Strategies to Strengthen Capacity Building

- Establish regular village-level training and demonstration programmes.
- Strengthen Farmer Field Schools and farmer-to-farmer learning.
- Train Community Resource Persons, Krishi Sakhis and extension workers.
- Develop simple manuals and visual materials in regional languages.
- Provide practical training on natural input preparation and soil health.
- Link farmers with KVKs, Agricultural Universities and research institutions.
- Encourage farmer groups for knowledge sharing and collective marketing.
- Use digital advisory services as a supporting tool.
- Provide follow-up visits and problem-solving support after training.
- Document successful local practices and evaluate them scientifically.
- capacity-building pathway in natural farming

Awareness → Training → Field Demonstration → Practice → Observation & Feedback → Farmer Confidence → Wider Adoption

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13. Conclusion

Capacity building is a central pillar for the successful development and spread of natural farming. Natural farming requires more than a change in inputs; it requires a change in knowledge, observation, planning and farm management. Training, demonstrations, Farmer Field Schools, farmer-to-farmer learning, extension support and institutional linkages can help farmers develop these abilities.

The experience of natural farming programmes in India and the wider Farmer Field School approach shows the value of practical, participatory and continuous learning. When farmers have the knowledge and confidence to observe their farms, test suitable practices and make informed decisions, capacity building can contribute to more sustainable and resilient agricultural systems.

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Natural Farming and Reduction of Agricultural Pollution

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Introduction

Natural farming is a farming system that works with nature instead of relying heavily on synthetic fertilizers, pesticides, and herbicides. It uses locally available resources, organic matter, crop diversity, mulching, composting, and biological processes to maintain soil fertility and plant health. The approach aims to produce food sustainably while protecting the environment and reducing pollution.

In modern agriculture, excessive use of chemical inputs has caused serious environmental problems such as soil degradation, water contamination, air pollution, and loss of biodiversity. Natural farming offers an alternative by lowering the dependence on synthetic inputs and encouraging eco-friendly practices. It is increasingly seen as a practical method for sustainable agriculture and climate-friendly food production.

Meaning of Natural Farming

Natural farming is a method of cultivation that avoids synthetic chemicals and depends on natural ecological processes. Instead of chemical fertilizers, farmers may use compost, green manure, crop residues, farmyard manure, bio-inputs, and natural microbial preparations. Instead of chemical pesticides, pest control is often achieved through crop rotation, mixed cropping, botanical extracts, habitat management, and biological balance.

The core idea is to build a self-sustaining agricultural system in which soil, water, plants, animals, and microorganisms support each other. This makes the farm more resilient and reduces the need for external industrial inputs. Natural farming is therefore not only a method of production but also a way of protecting natural resources.

Major Sources of Agricultural Pollution

Agricultural pollution happens when farming activities release harmful substances into soil, water, and air. One major source is the excessive application of chemical fertilizers, which can lead to nutrient runoff into rivers, lakes, and groundwater. This runoff contributes to water pollution and eutrophication, which damages aquatic ecosystems.

Another major source is pesticide use. Pesticides may remain in soil, move into water bodies, and affect insects, birds, fish, and human health. Farm machinery, fertilizer manufacture, and intensive tillage also contribute to greenhouse gas emissions and air pollution. Over time, these practices can reduce soil quality, increase erosion, and weaken ecosystem stability.

How Natural Farming Reduces Pollution

Natural farming reduces pollution in several direct and indirect ways. First, it avoids or greatly reduces synthetic fertilizer use, which lowers the risk of nitrogen and phosphorus runoff into water bodies. This helps protect groundwater and surface water from contamination.

Second, natural farming minimizes pesticide pollution by using biological and ecological pest management instead of harmful chemical sprays. This reduces toxic residues in food, soil, and water. Third, practices such as mulching, cover cropping, and composting improve soil structure and reduce

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erosion, which means fewer pollutants are washed away during rainfall.

Fourth, natural farming can reduce greenhouse gas emissions because it decreases dependence on industrial fertilizers, whose manufacture and application are energy-intensive. Some studies report that natural farming can lower input energy needs and emissions substantially compared with conventional farming, especially when applied effectively across crops and regions.

Soil Health Benefits

Healthy soil is the foundation of sustainable agriculture. Natural farming improves soil by adding organic matter, increasing microbial activity, and supporting better nutrient cycling. Practices like composting, mulching, crop rotation, and intercropping help maintain soil fertility without exhausting the land.

Soil under natural farming often has better structure, improved water-holding capacity, and lower erosion risk. These improvements help crops survive dry periods and reduce the need for irrigation in some cases. Research also suggests that natural farming can increase soil organic carbon, which supports long-term productivity and helps trap carbon in the soil.

Water Conservation and Protection

Water pollution is one of the biggest environmental problems linked to chemical farming. Fertilizer and pesticide runoff can enter rivers, ponds, and groundwater, making water unsafe for people and harmful for aquatic life. Natural farming reduces this problem because it relies less on synthetic chemicals and more on organic soil management.

Natural farming also helps conserve water. Healthy soils with more organic matter can absorb and retain more moisture, reducing water loss through runoff and evaporation. In some studies, natural farming systems required significantly less irrigation water than chemical-based farming, especially in crops such as paddy, groundnut, chili, cotton, and maize. This makes natural farming especially valuable in dry and water-stressed regions.

Biodiversity Conservation

Biodiversity is essential for stable ecosystems and productive farms. Natural farming supports biodiversity by reducing chemical harm to beneficial insects, soil organisms, birds, and small animals. It also encourages crop diversification, which creates a more balanced agricultural landscape.

When farms include multiple crops, borders, trees, and habitat-friendly practices, they support pollinators and natural pest enemies. This reduces the need for chemical pesticides and improves ecological balance. Biodiversity conservation is one of the strongest environmental advantages of natural farming because it protects both farm productivity and surrounding ecosystems.

Climate Change Mitigation

Natural farming can also help address climate change. Synthetic fertilizer production and use release greenhouse gases, especially nitrous oxide, which is a powerful warming gas. By reducing chemical fertilizer dependency, natural farming lowers these emissions.

In addition, organic matter management in natural farming increases carbon sequestration in soil. This means more carbon is stored underground rather than released into the atmosphere. A more carbon-rich soil is usually more fertile, more stable, and better able to support crops under climate stress.

Economic and Social Value

Natural farming is not only environmentally useful but also economically helpful for many farmers. Since it reduces the purchase of chemical fertilizers and pesticides, it can lower input costs. Farmers may become less dependent on market fluctuations in agrochemical prices and more reliant on local resources.

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It also supports safer food production and healthier rural environments. Reduced chemical exposure benefits farm workers, consumers, and nearby communities. Over time, this can improve the sustainability of agriculture and make farming systems more self-reliant and resilient.

Challenges in Adoption

Despite its benefits, natural farming has some challenges. Farmers may need training to manage pests, soil fertility, and crop nutrition without chemical inputs. During the transition period, yields may be uncertain in some regions, and results can vary depending on soil type, climate, and management skill.

Another challenge is that long-term scientific evaluation is still needed in many places. More research is required to measure its impact on yield stability, soil health, water use, biodiversity, and emissions under different farming systems. Even so, the available evidence shows strong environmental promise.

Conclusion

Natural farming is an eco-friendly farming system that reduces agricultural pollution by minimizing synthetic fertilizer and pesticide use. It protects soil, water, air, biodiversity, and human health while supporting long-term sustainability.

By improving soil health, conserving water, reducing emissions, and encouraging biodiversity, natural farming offers a practical pathway toward cleaner and more resilient agriculture. It is not only a farming method but also an important strategy for reducing pollution and protecting natural resources for future generations.

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Increasing fodder productivity under rabi Season water scarcity

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Rabi-season fodder production is often affected by limited rainfall and restricted irrigation water. Water scarcity can reduce crop establishment, vegetative growth, biomass production and regrowth after cutting. Increasing fodder productivity under these conditions requires a water-efficient approach that combines suitable crop and variety selection, timely sowing, soil-moisture conservation, efficient irrigation, balanced nutrient management, weed control and timely harvesting. Crops such as oat, fodder barley, berseem and lucerne can be selected according to local climate, soil and available irrigation. Priority should be given to maintaining moisture during establishment and other critical growth stages while avoiding unnecessary irrigation losses. Good agronomic management can increase useful fodder production per unit of available water and support livestock feed availability during the Rabi season.

Introduction

Fodder crops are grown to provide green and dry feed for livestock. During the Rabi season, low rainfall, limited irrigation water, dry winds and competition for available water can reduce fodder growth and quality. The main objective under water scarcity is therefore to produce more useful fodder per unit of water while maintaining acceptable nutritive value.

Objectives

- Increase green fodder and dry matter production with limited irrigation.
- Use drought-tolerant and relatively water-efficient fodder crops and varieties.
- Improve soil moisture conservation and reduce unnecessary water loss.
- Schedule irrigation according to crop need and critical growth stages.
- Maintain fodder quality by timely harvesting and proper crop management.

Suitable Rabi fodder crops

Crop	Important feature under limited water
Lucerne (alfalfa)	Perennial legume; high-quality fodder; needs careful irrigation scheduling.
Berseem	Winter legume with good fodder quality; performs best where some irrigation is available.
Oat	Important winter fodder cereal; good green fodder and relatively flexible in cultivation.
Ryegrass	Useful winter fodder; good quality, but moisture availability affects establishment and regrowth.
Fodder barley	Winter cereal that can provide fodder under comparatively limited-water conditions.

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1. **Crop establishment and soil-moisture management**

Timely sowing

Timely sowing allows the fodder crop to establish before severe moisture stress develops. In Rabi, sowing should be planned according to the recommended sowing window for the crop and local climate. Delayed sowing may shorten the effective growing period and reduce biomass production.

Selection of suitable crop and variety

- Prefer locally recommended varieties with good fodder yield and adaptation to the winter environment.
- Where irrigation is restricted, choose crops that fit the available water supply and expected duration of the Rabi season.
- Legume–cereal combinations can improve the balance between fodder quality and yield when locally recommended.

Seed quality and seed treatment

Use clean, viable seed with good germination. For legume fodders, appropriate Rhizobium inoculation can support biological nitrogen fixation and improve nitrogen nutrition. Seed treatment should follow the crop-specific recommendation.

Land preparation and soil moisture conservation

- Prepare a reasonably fine, firm seedbed so that seed has good contact with moist soil.
- Avoid excessive tillage because repeated disturbance can increase evaporation and destroy soil structure.
- Use crop residues or suitable organic mulches where practical to reduce direct evaporation and moderate soil temperature.
- Maintain field channels and bunds where appropriate to reduce runoff and improve the use of irrigation water.

Weed management

Weeds compete with fodder crops for water, nutrients and light. Early weed control is especially important under water scarcity because water used by weeds is unavailable to the fodder crop. Use timely hand weeding, interculture or crop-specific herbicide recommendations where appropriate.

Why establishment matters

A uniform plant stand develops a larger effective canopy and root system, helping the crop use available water and nutrients efficiently. Poor establishment creates gaps, encourages weeds and lowers fodder yield per unit area.

2-Efficient irrigation and nutrient management

Irrigation scheduling

Under water scarcity, irrigation should be applied according to crop demand rather than on a fixed calendar whenever possible. The most useful approach is to prioritize sensitive growth stages and avoid unnecessary irrigation when soil moisture is adequate.

- Give irrigation at sowing or establishment when required for uniform germination.
- Prioritize irrigation during early establishment and other critical growth stages identified for the crop.
- Avoid over-irrigation, waterlogging and very frequent shallow irrigation because they can waste water and reduce root development.
- Check soil moisture before irrigation; simple field observation can help identify whether the root zone is becoming too dry.
- Where available, use efficient irrigation methods such as drip or sprinkler systems according to crop suitability and local recommendations.

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Critical stages and water-saving strategy

Management stage	Action under water scarcity
Before sowing	Conserve available soil moisture; prepare seedbed efficiently.
Establishment	Protect germination and early root growth; avoid moisture stress.
Vegetative growth	Irrigate only when needed and control weeds promptly.
Pre-harvest	Maintain sufficient moisture for acceptable biomass and quality; avoid excessive irrigation.

Balanced nutrient management

Adequate nutrition helps the crop convert available water into biomass. Soil testing is the preferred basis for fertilizer recommendations. Nitrogen, phosphorus, potassium and other nutrients should be supplied according to crop requirement and local recommendations rather than applying excess fertilizer.

- Legume fodders can obtain part of their nitrogen through biological fixation when effective root nodulation occurs.
- Phosphorus supports root development and is particularly important in establishing legumes.
- Potassium contributes to plant water relations and overall crop functioning; apply it according to soil-test and crop recommendations.
- Avoid excessive nitrogen because it can increase unnecessary vegetative growth and fertilizer losses.

Organic matter and soil health

Farmyard manure, compost and other locally suitable organic amendments can improve soil structure and water-holding capacity when used properly. Their effect is gradual, so they should complement—not replace—efficient irrigation and other agronomic practices.

3. Harvesting, integrated practices and conclusion

Timely harvesting

Harvesting at the recommended stage is essential for both yield and fodder quality. Very early harvesting may reduce total biomass, while very late harvesting can increase fibre content and reduce palatability and digestibility. The optimum stage differs among crops, so crop-specific recommendations should be followed.

Multi-cut and regrowth management

For multi-cut fodders, the first cut and subsequent cuts should be timed to allow sufficient regrowth. After cutting, avoid severe moisture stress during early regrowth. Efficient irrigation during the most important regrowth stages can improve water productivity.

Water-saving agronomic practices – summary

Practice	Expected benefit
Timely sowing	Better establishment and longer effective growing period.
Suitable crop/variety	Better adaptation to local winter and water conditions.
Moisture conservation	Less evaporation and better use of stored soil water.
Efficient irrigation	Less water loss and better water productivity.
Weed control	Reduces competition for water and nutrients.

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Balanced fertilization	Supports efficient conversion of water and nutrients into biomass.
Timely harvest	Maintains useful yield and fodder quality.

4. Integrated package for Rabi water scarcity

- Select a locally recommended, water-efficient fodder crop or variety that matches the available irrigation supply.
- Sow at the appropriate Rabi time using good-quality seed and a well-prepared seedbed.
- Conserve soil moisture and keep the crop weed-free during early growth.
- Schedule irrigation based on soil moisture and critical crop stages, giving priority to establishment and sensitive stages.
- Use soil-test-based, balanced fertilization and suitable biofertilizer practices for legumes.
- Harvest at the recommended stage and manage regrowth carefully in multi-cut crops.
- Record irrigation, yield and fodder quality to identify the most water-efficient practice for the farm.

Conclusion

Increasing fodder productivity during a water-scarce Rabi season depends mainly on improving water-use efficiency rather than simply increasing irrigation. The combined use of suitable fodder crops, timely sowing, moisture conservation, efficient irrigation, weed control, balanced nutrition and timely harvesting can maintain useful fodder production with limited water. Proper management also supports better crop establishment, regrowth and fodder quality. Therefore, an integrated water-saving agronomic package is essential for sustainable Rabi fodder production, especially in areas where irrigation resources are limited. Crop choice, irrigation interval and fertilizer dose should be adjusted to local soil, climate and recommended agricultural practices.

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Nitrogen Use Efficiency (NUE) in Sugarcane and Intensive Cropping Systems

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Nitrogen (N) is a critical macro-nutrient required for achieving high yield and biomass in intensive agricultural systems. However, Nitrogen Use Efficiency (NUE) in crop production—especially in high-demand crops like sugarcane and intensive multi-cropping systems—remains low, typically ranging between 30% and 50%. The unabsorbed nitrogen is lost through volatilization, denitrification, leaching, and runoff, leading to economic losses for farmers and severe environmental issues such as groundwater nitrate contamination and greenhouse gas emission (N_2O). This document covers NUE mechanisms, soil dynamics, factors contributing to losses, and integrated management practices—including agronomic techniques, fertilizer technologies, and genetic strategies—to maximize nitrogen efficiency in sugarcane and intensive crop rotations.

Introduction

Nitrogen plays a vital role in plant physiology, driving photosynthetic activity, protein synthesis, canopy expansion, and overall biomass production. To feed a growing global population, modern agriculture relies heavily on synthetic nitrogenous fertilizers. However, intensive cropping systems—characterized by high cropping intensity, frequent tillage, heavy irrigation, and high fertilizer application rates—often suffer from low nitrogen recovery.

Sugarcane (*Saccharum officinarum*) is a long-duration, high-biomass C4 crop that requires substantial nitrogen inputs (often exceeding 150–300 kg N/ha depending on regional soil and target yield). Because sugarcane remains in the field for 10 to 18 months and experiences distinct growth phases, matching nitrogen supply with crop demand is challenging. Furthermore, sugarcane ratoon crops often exhibit lower NUE than plant crops due to root biomass dynamics and soil compaction.

In intensive cropping systems (such as Rice-Wheat, Sugarcane-Ratoon-Wheat, or Maize-Legume systems), improper timing, over-application, and inefficient application methods exacerbate nitrogen losses. Improving NUE is therefore essential to harmonize agricultural productivity with environmental sustainability.

1. Understanding Nitrogen Use Efficiency (NUE)

Definition and Indices

NUE measures how effectively crops take up and utilize available nitrogen to produce economical yield or biomass. Key quantitative expressions include:

- **Agronomic Efficiency (AE_N):** Economic yield increase per unit of N applied (\text{kg yield / kg N applied}).
- **Apparent Recovery Efficiency (RE_N):** Percentage of applied N taken up by the plant (\text{kg N uptake difference / kg N applied} \times 100).
- **Physiological Efficiency (PE_N):** Yield produced per unit of N absorbed by the crop (\text{kg yield / kg N absorbed}).
- **Internal Utilization Efficiency (IE_N):** Economic yield per unit of total N uptake.

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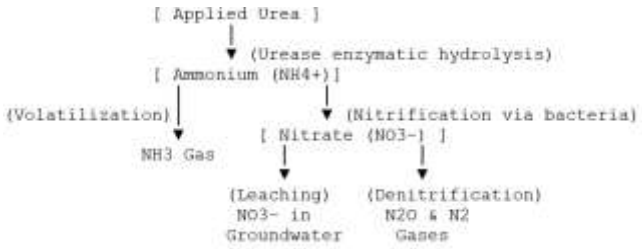
2. Nitrogen Dynamics and Loss Pathways

When nitrogen fertilizers (e.g., Urea, Ammonium Sulfate) are applied to the soil, nitrogen undergoes rapid chemical and biological transformations:



Major Loss Pathways:

1. **Ammonia Volatilization (NH_3):** High soil pH, warm temperatures, and surface application of urea favor NH_3 gas escape into the atmosphere.
2. **Nitrate Leaching (NO_3^-):** Nitrate is negatively charged and does not bind to soil particles. Heavy irrigation or rainfall washes NO_3^- below the root zone into groundwater.
3. **Denitrification (N_2O and N_2):** In waterlogged or anaerobic conditions, soil microbes convert NO_3^- into nitrous oxide (N_2O, a potent greenhouse gas) and dinitrogen gas (N_2).
4. **Surface Runoff:** Heavy rainfall immediately following surface fertilizer application carries dissolved N away into open water bodies.

3. NUE in Sugarcane Systems

Nitrogen Demand Profile in Sugarcane

Sugarcane exhibits four distinct physiological growth stages:

1. **Germination / Establishment (0–60 days):** Low nitrogen requirement; relies largely on seed-cane reserves.
2. **Tillering Phase (60–120 days):** High nitrogen demand to establish tillers and canopy leaf area.
3. **Grand Growth Phase (120–270 days):** Peak nitrogen uptake for stalk elongation and biomass accumulation.
4. **Maturity & Ripening (270+ days):** Low N requirement. Excess late-stage N reduces sucrose accumulation and juice purity.

Key Challenges in Sugarcane:

- **Mismatched Timing:** Applying large single doses of fertilizer during planting leads to severe leaching losses before the root system matures.
- **Ratoon Crop Efficiency:** Ratoon crops often face trash/residue cover, compacted soils, and poor root distribution, leading to lower nitrogen absorption compared to plant sugarcane.
- **Over-fertilization:** High N doses near harvest boost vegetative growth at the expense of sugar content (Brix/CCS).

4. NUE in Intensive Cropping Systems

Intensive cropping systems maximize land productivity by growing two to three crops per year on the same field.

Factors Lowering NUE in Intensive Systems:

- **Soil Degradation & Compaction:** Frequent tillage reduces soil organic matter, impairing root growth and soil microbial health.
- **Water Management Inefficiencies:** Continuous flood irrigation accelerates leaching and denitrification.
- **Residual Nitrogen Management:** Nitrogen left behind by previous crops (especially legumes) is often ignored, leading to compounding over-application.

5. Integrated Strategies to Enhance NUE

Improving NUE requires combining agronomic practices, modified fertilizer technologies, and genetic approaches:

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A. The "4R" Nutrient Stewardship

- **Right Source:** Matching fertilizer type to soil pH and crop stage (e.g., using ammonium-based fertilizers in alkali soils, or slow-release forms).
- **Right Rate:** Soil testing, leaf tissue testing, or optical sensors (SPAD meters, GreenSeeker NDVI) to avoid excess application.
- **Right Time:** Splitting nitrogen into 3–4 applications matching crop demand phases (e.g., tillering and early grand growth in sugarcane).
- **Right Place:** Deep placement or band application beneath the soil surface rather than broad broadcast.

B. Fertilizer Technologies

- **Nitrification Inhibitors (NIs):** Chemicals like DCD or Nitrapyrin delay the conversion of NH_4^+ to NO_3^-, minimizing leaching and denitrification.
- **Urease Inhibitors (NBPT):** Slow down urea hydrolysis, reducing ammonia volatilization.
- **Controlled / Slow-Release Fertilizers:** Polymer-coated or sulfur-coated urea releases N gradually over several months.
- **Neem-Coated Urea (NCU):** Botanical coatings that act as natural nitrification inhibitors.

C. Agronomic & Cultural Practices

- **Trash Mulching & Management in Sugarcane:** Retaining crop residues improves soil moisture, adds organic matter, and regulates nitrogen mineralization.
- **Incorporating Legumes:** Crop rotations including legumes (e.g., mung bean, cowpea, sunn hemp) fix atmospheric nitrogen naturally, reducing chemical N requirements for subsequent crops.
- **Precision Irrigation:** Drip fertigation supplies water and nitrogen directly to the root zone in micro-doses, reducing leaching by up to 40–50%.

Conclusion

Maximizing **Nitrogen Use Efficiency (NUE)** in sugarcane and intensive cropping systems is necessary to maintain high crop productivity while minimizing environmental damage. Low NUE is rarely caused by a single factor, but rather by systemic mismatches between nitrogen supply and crop demand, combined with unfavorable soil and water management practices.

Adopting **4R Nutrient Stewardship**, precision fertigation, slow-release or coated fertilizers, trash retention, and legume crop rotations can substantially raise nitrogen recovery rates. Enhancing NUE ensures higher farmer profitability through reduced input costs, preserves soil health, and protects air and water ecosystems from nitrogen pollution.

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Precision Nutrient Management in Sugarcane (*Saccharum officinarum* L.): Current Status, Technological Interventions, and Future Research Perspective

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Sugarcane (*Saccharum officinarum* L.) is a high-biomass, long-duration agro-industrial crop requiring substantial macronutrient and micronutrient inputs to optimize both cane yield and commercial cane sugar (CCS) percentage. Traditional blanket fertilizer practices suffer from low Nutrient Use Efficiency (NUE)—recovering less than 40% of applied nitrogen—leading to severe soil degradation, underground water pollution, and escalated production costs. **Precision Nutrient Management (PNM)** addresses spatio-temporal soil variability through targeted application technologies based on the 4R Stewardship Principles: Right Source, Right Rate, Right Time, and Right Place.

This review highlights the current status of PNM technologies implemented in sugarcane cultivation, such as Variable Rate Technology (VRT), Remote and Proximal Optical Sensing, Site-Specific Nutrient Management (SSNM), dynamic fertigation models, and Machine Learning (ML)-driven soil health monitoring. Despite high preliminary success in boosting recovery rates and reducing input costs, adoption remains constrained by high capital barriers, smallholder field fragmentation, and complex spatial data processing. Future prosperity in PNM lies in AI-driven predictive modeling, Internet-of-Things (IoT) dynamic sensor arrays, Autonomous Aerial Application Systems (UAVs), and customized nano-formulations.

2.Introduction

Sugarcane serves as the primary global source of sugar and bioethanol, contributing heavily to rural economies and renewable energy strategies. Due to its extended growth cycle (10 to 18 months) and continuous accumulation of vegetative mass, the crop extracts significant amounts of macronutrients—typically requiring 1.5 to 2.5 kg of Nitrogen (N), 0.5 to 0.8 kg of Phosphorus (\text{P}_2\text{O}_5), and 2.0 to 3.0 kg of Potassium (\text{K}_2\text{O}) per metric ton of stalk produced.

Historically, farmers relied on static, regional fertilizer recommendations applied via surface broadcasting. This approach neglects spatial soil variation, field micro-climates, and dynamic physiological crop demand, causing significant nutrient losses through:

- **Ammonia volatilization** and **nitrate leaching** into groundwater.
- **Nutrient immobilization** in calcareous or highly acidic soils.
- **Gaseous emissions** (\text{N}_2\text{O}) that exacerbate climate change.

Precision Agriculture (PA) replaces static schedules with site-specific agronomic practices. By matching nutrient delivery to real-time crop uptake, Precision Nutrient Management (PNM) aims to maximize economic returns while minimizing environmental footprints.

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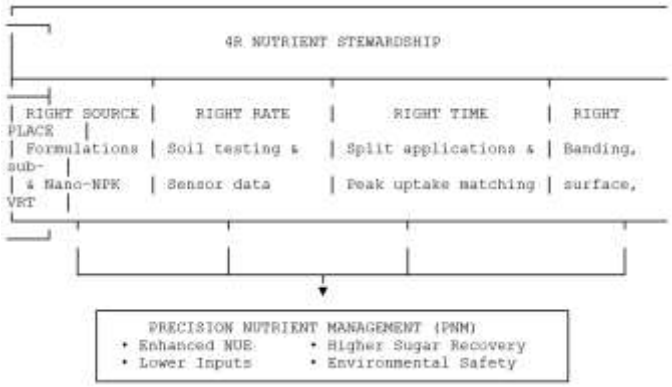

3. Spatial and Temporal Soil Nutrient Variability in Sugarcane Fields

Sugarcane fields exhibit significant within-field variability driven by topography, historical management, soil texture, organic carbon content, and soil pH.

Soil Heterogeneity Factors

- **Physical Constraints:** Variations in clay content, compaction layers, and water-holding capacity directly impact root extension and nutrient mobility.
- **Chemical Heterogeneity:** Calcareous soils induce Micronutrient (Fe, Zn) fixation, while low-pH soils suffer from Phosphorus binding.
- **Yield Clutter:** Multi-year ratoon cropping alters root zone architecture, creating uneven nutrient depletion patterns.

Traditional composite soil sampling masks these micro-variations, leading to **over-fertilization in high-fertility zones** and **under-fertilization in nutrient-deficient areas**. Precision management maps these zones using grid sampling (1–2 ha blocks), Electrical Conductivity (EC) directed sampling, and yield-map overlays to build precise Prescription Maps.

4. Current Technological Status of Precision Nutrient Management

CURRENT PNM TECHNOLOGICAL SUITE		
SENSING & MAPS	APPLICATION	DECISION SUPPORT
• UAV Multi-spectral • Satellite (NDVI) • Optical Sensors	• Drip-Fertigation • VRT Spreading • Deep Banding	• Soil test tools • AI / Crop Models • SSNM Software

Optical Sensing and Canopy Diagnostics

Proximal and remote sensors evaluate real-time crop nitrogen status by measuring chlorophyll reflectance:

- **Satellite Remote Sensing:** Multi-spectral imagery from Sentinel-2 and Landsat-8 provides Normalized Difference Vegetation Index (NDVI) and Green NDVI (GNDVI) maps to track crop vigor across large areas.
- **Proximal Canopy Sensors:** Tractor-mounted active optical sensors (e.g., GreenSeeker, Crop Circle) measure real-time canopy light absorption and compute Nitrogen Sufficiency Indexes (NSI) during field passes.
- **UAV Multi-Spectral Imaging:** Drones provide high-resolution (<5\text{ cm/pixel}) diagnostics, detecting early micro-nutrient deficits before visible chlorosis appears.

Variable Rate Technology (VRT) and Application Machinery

VRT hardware automatically regulates fertilizer flow rates based on GPS-referenced prescription maps or real-time sensor feedback:

- **Map-Based VRT:** Pre-computed soil map data directs hydraulic or electric spreaders to adjust N, P, and K delivery across management zones.
- **Sensor-Based VRT:** On-the-go algorithm-driven applicators adjust nitrogen output instantly based on live optical sensor readings.
- **Sub-surface Band Placement:** Placing fertilizers at a depth of 10–15 cm beside sugarcane clumps reduces gaseous losses and

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improves N and K uptake efficiency compared to surface broadcasting.

Precision Fertigation via Subsurface Drip Irrigation (SDI)

Subsurface Drip Irrigation (SDI) combined with fertigation allows precise delivery of water-soluble nutrients directly into the active root zone:

- Minimizes nutrient volatilization and deep percolation.
- Enables micro-dosing across critical growth windows (germination, tillering, and grand growth phases).
- Achieves up to **25–30% fertilizer savings** while boosting cane yield by **15–20%** compared to surface flooding.

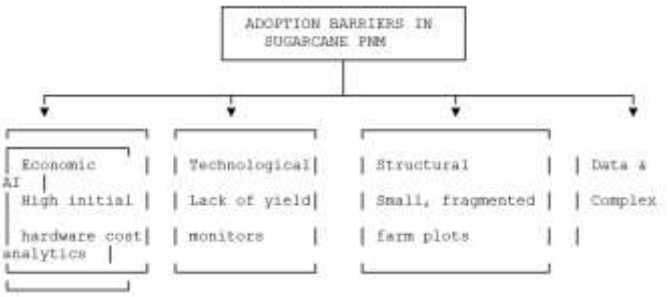
Nutrient Management Method	Nitrogen Use Efficiency (%)	Yield Impact vs. Standard	Environmental Risk
Blanket Surface Broadcasting	25 - 35\%	Baseline	**High** (Leaching, Volatilization)
Split-Banding (4–7 Splits)	45 - 55\%	+15 \text{ to } 20\%	**Moderate**
Drip Fertigation (SDI)	65 - 80\%	+25 \text{ to } 35\%	**Low**
VRT + Sensor-Guided Delivery	70 - 85\%	+20 \text{ to } 30\%	**Very Low**

5. Decision Support Systems and Site-Specific Nutrient Management (SSNM)

Site-Specific Nutrient Management (SSNM) replaces fixed recommendations with dynamic field-level guidance using field history, target yields, and local climate data:

- **Nutrient Expert® for Sugarcane:** An interactive decision-support tool that uses Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) principles to calculate customized N-P-K requirements.
- **Crop Growth Simulation Models:** Tools like APSIM-Sugarcane and CANEGRO simulate crop growth, soil water movement, and organic matter mineralization to optimize top-dressing timing.
- **Soil Test Crop Response (STCR) Models:** Targeted yield equations ensure nutrient applications match specific soil test values and yield goals.

6. Challenges and Barriers to Large-Scale Adoption



1. **High Initial Capital Cost:** Advanced VRT spreaders, RTK-GPS guidance, UAVs, and subsurface drip systems require substantial up-front investments that often outreach smallholder budgets.
2. **Lack of Commercial Sugarcane Yield Monitors:** Unlike grain crops, sugarcane's high bulk density, variable stalk geometry, and heavy harvester abrasion make real-time yield monitoring difficult, slowing precise field-mapping efforts.
3. **Smallholder Land Fragmentation:** In developing countries, small and non-contiguous field plots make deploying large VRT machinery economically and logistically challenging.

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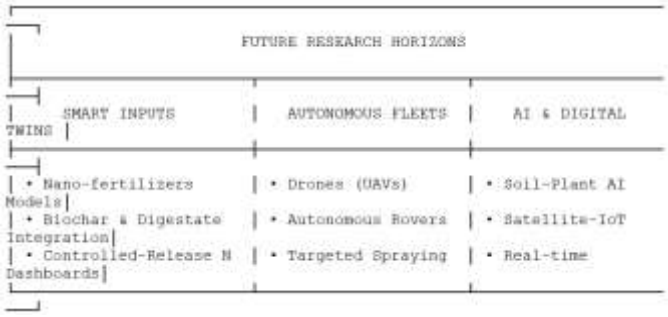
4. **Data Management Complexity:** Translating raw GIS layers, hyperspectral flight data, and soil tests into simple prescription maps requires technical expertise that many extension systems lack.

5. **Dense Canopy Barrier:** Late-stage sugarcane forms an impenetrable vegetative canopy up to 4 meters high, restricting ground-based mid-to-late season machinery passes.

7. Research Prosperity and Future Horizons

To overcome current barriers, precision nutrient management research focuses on smart inputs, autonomous systems, and predictive modeling.



1. Artificial Intelligence and Machine Learning Integration

Future frameworks will merge high-resolution satellite imagery, real-time IoT soil sensors, and local weather forecasts into unified AI pipelines. These models predict nutrient stress early, triggering automated fertigation or aerial dosing protocols before yields are affected.

2. Autonomous Aerial Application Systems (UAVs)

Heavy agricultural drones overcome late-season canopy access limitations. Swarms of autonomous UAVs equipped with multi-spectral vision and targeted liquid sprayers can diagnose and address nutrient deficiencies deep into the grand growth phase.

3. Nano-Fertilizers and Smart Controlled-Release Formulations

Advanced nano-formulations (e.g., nano-urea, nano-zinc, and biopolymer-coated slow-release granules) deliver nutrients in response to root exudates, reducing leaching and volatilization losses while maximizing cellular absorption.

4. Circular Bio-Economy and Organic Integration

Integrating bio-based amendments—such as biochar, biogas digestate, press mud, and boiler ash—with synthetic fertilizers improves soil structure, microbial activity, and long-term organic carbon storage.

8. Conclusion

Precision Nutrient Management (PNM) provides a practical pathway to move sugarcane production away from resource-intensive blanket fertilization toward unsustainable environmental degradation. Integrating diagnostic sensing, site-specific nutrient tools, variable-rate machinery, and subsurface fertigation significantly improves Nutrient Use Efficiency (NUE), lowers input costs, and protects regional soil and water resources.

Accelerating global adoption requires policy support, shared equipment hubs, custom hiring centers for smallholders, and open-access digital advisory services. Bridging the gap between advanced digital agronomy and field-level implementation will help ensure the long-term economic stability and environmental sustainability of the global sugarcane industry.

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Climate Change and in Impact on Groundnut Productivity

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This study examines the impacts of climate change and variability on groundnut (*Arachis hypogaea* L.) productivity. Rising global temperatures, erratic rainfall, and prolonged droughts disrupt critical crop growth stages, including germination, flowering, and pod formation. Elevated daytime and nighttime temperatures induce heat stress, impairing plant physiology and lowering overall pod yields. Additionally, shifting humidity and moisture levels foster favorable conditions for fungal infections, such as aflatoxin contamination, and aggravate pest infestations. Crop simulation models and regional data indicate that unmitigated climate trends could lead to substantial yield losses, threatening food security and farmers' livelihoods. The findings emphasize the urgent need for climate-smart agricultural practices, including the adoption of heat-tolerant groundnut varieties, optimized sowing schedules, and improved water management strategies to build long-term farming resilience.

Introduction

Groundnut is one of the most important oilseed crops in India and many tropical and semi-arid regions of the world. It provides edible oil, protein, fodder, and income to farmers, especially in rainfed areas where crop production depends heavily on seasonal rainfall. Because of this, groundnut is highly exposed to climate variability and long-term climate change. Climate change affects not only the yield of the crop, but also its growth duration, reproductive success, seed quality, pest and disease incidence, and economic return.

Importance of groundnut

Groundnut is cultivated widely in marginal, arid, and semi-arid agro-ecosystems where rainfall is uncertain and soils are often poor in moisture retention. In such environments, even slight changes in temperature or rainfall can produce major changes in pod yield. The crop is also very important because it fits into multiple farming systems and contributes to food security and farmer livelihood. Therefore, understanding the climate change impact on groundnut is important for both production planning and adaptation strategy development.

Meaning of climate change in groundnut

Climate change in groundnut production refers to long-term changes in temperature, rainfall pattern, atmospheric CO2 concentration, and the frequency of extreme events such as drought, heat waves, heavy rainfall, and humidity stress. These changes influence crop growth at every stage from germination to harvest.The overall effect is usually complex because some factors may be harmful while others may have partial benefits. For example, increased atmospheric CO2 can improve photosynthesis, but this advantage is often outweighed by heat and moisture stress.

Why groundnut is vulnerable

Groundnut is especially vulnerable because it is commonly grown under rainfed conditions in warm regions.Its yield depends on timely rainfall and moderate temperatures during flowering, pegging, pod formation, and seed filling .When climate change causes drought, heat stress, or rainfall irregularity

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during these sensitive stages, the crop suffers heavy loss .The crop also grows in soils that may already have limited water-holding capacity, so E

Effects of higher temperature

Rising temperature is one of the most direct climate threats to groundnut.High temperature shortens the crop duration, speeds up development, and reduces the time available for pod filling.This can reduce the accumulation of dry matter in pods and kernels, resulting in lower yield .Very high temperatures can also reduce flower retention, impair pollination and fertilization, and disturb assimilate partitioning to pods. Simulation studies in India found that increased temperature significantly decreased pod yield at all studied sites.

Effects of drought stress

Drought is one of the most damaging stresses for groundnut because the crop is often grown where rainfall is limited and unpredictable. Water stress reduces germination, seedling establishment, vegetative growth, flowering, peg formation, peg penetration into the soil, and pod development . If drought occurs during flowering and pod filling, the reduction in yield is especially severe. Drought also reduces leaf area, yield becomes highly unstable and economic risk increases for farmers .

Effects of erratic rainfall

Climate change is expected to increase both the variability and unpredictability of rainfall .For groundnut, this creates two major problems: first, delayed or insufficient rainfall causes drought-like stress, and second, intense rainfall can cause temporary waterlogging or soil saturation. Waterlogging can reduce root respiration, interfere with nutrient uptake, and weaken crop growth . Erratic rainfall can also make it difficult to sow at the right time, which affects crop establishment and final yield.Therefore, rainfall instability can harm productivity even when total seasonal rainfall appears normal.

Effects of elevated CO2

Higher atmospheric CO2 can stimulate photosynthesis and improve biomass production in groundnut to some extent. This may partially help the crop under future climate scenarios. However, the benefit is often limited because groundnut productivity is constrained more strongly by heat, moisture stress, and extreme weather than by CO2 alone. In practical terms, CO2 fertilization may slightly soften losses, but it does not eliminate the negative effects on climate change.

Effect on growth stages

Groundnut growth is affected differently at different stages. During germination and early vegetative growth, moisture deficiency can reduce plant population and stand uniformity. During flowering, heat and drought can lower flower formation and retention. During pegging, soil moisture is crucial because pegs must penetrate the soil to form pods/. During pod filling and seed development, both heat and water stress reduce kernel size, dry matter accumulation, and final yield. Thus, stress at any critical stage can reduce productivity, but stress during reproductive stages is generally the most damaging.

Impact on yield

Yield reduction is the most visible effect of climate change on groundnut. Model-based studies show that theimpact varies by region, climate scenario, and management. One Indian study reported that by 2050, climate change could lead to a **34% decrease to 43% increase** in yield across different regions depending on assumptions and scenarios. Another study found a **4% decrease at Anantapur** and **11% increase at Mahboobnagar and Junagadh** when temperature, rainfall, and CO2 were combined. This means climate change does not affect all production zones equally, and local adaptation is essential.

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Regional variation in impact

The impact of climate change on groundnut is not uniform across India or other countries. In some districts, projected rainfall changes and CO2 benefits may partly compensate for temperature stress, leading to small gains .In other dry regions, heat and drought may dominate and cause serious losses. This spatial variation is important because it shows that recommendations must be location-specific rather than general. The same adaptation practice may work well in one area but give limited benefit in another.

Effect on pod and kernel development

Pod and kernel formation are among the most sensitive processes in groundnut. Climate stress during these stages reduces the number of mature pods, lowers kernel size, and decreases shelling percentage. Seed-filling duration may become shorter under high temperature, reducing the weight of individual seeds. In addition, poor assimilate allocation under stress means that more biomass remains in leaves and stems instead of being transferred to pods As a result, both biological yield and economic yield decline.

Effect on quality

Climate change affects not only quantity but also quality of groundnut produce. High temperature and water stress can reduce seed size, alter oil accumulation, and affect kernel quality. Poor filling may reduce market value and processing quality. In oilseed crops like groundnut, any reduction in kernel development can also affect oil recovery and overall economic return. Therefore, climate stress can cause hidden losses even when the crop appears to survive in the field.

Pest and disease pressure

Climate change can increase the incidence and severity of pests and diseases in groundnut. Warmer temperatures and changing humidity patterns may favor certain insect pests and pathogens. Pest outbreaks weaken plants, reduce leaf area, and lower pod yield. Disease pressure may also rise when rainfall and humidity patterns become irregular. This increases production cost because farmers need more crop protection measures.

Economic and social impact

The climate impact on groundnut is not only biological but also economic. Lower yields reduce farm income, especially in rainfed regions where farmers have limited irrigation support. Yield instability increases risk, making it harder for farmers to plan input use, credit repayment, and market sales. Climate-induced production loss can also affect local oilseed supply and rural livelihood security. In this way, climate change creates a chain effect from field level to household and market level.

Adaptation through breeding

Breeding climate-resilient varieties is one of the most important long-term solutions. Studies suggest that groundnut cultivars with better drought tolerance, heat tolerance, and higher yield potential can reduce climate losses. In one study, increasing crop maturity by 10% improved yield under some sites, while combining drought and heat tolerance gave stronger gains under climate change. Modern breeding approaches include selection of QTLs, marker-assisted breeding, genomics, speed breeding, and transgenic approaches. These methods can help develop varieties suited for future climate conditions.

Adaptation through agronomy

Agronomic adaptation is equally important and often gives faster results than breeding alone. Supplemental irrigation can greatly improve yield when rainfall is insufficient. Adjusting sowing time helps the crop avoid the most severe stress periods. Longer-duration or better-adapted varieties can use available moisture more effectively. Crop residue application and soil moisture conservation also help buffer the crop against drought. These practices work best when selected according to local climate and soil conditions.

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Adaptation through management tools

Decision support systems, crop simulation models, and GIS tools are increasingly used to study climate risk and design adaptation measures. The CROPGRO-Groundnut model has been used widely to understand climate effects and test different management options. Such models help estimate yield under future climate scenarios and identify the best adaptation strategy for each region. This is useful for extension workers, researchers, and policy makers because it improves planning and reduces uncertainty. Model-based planning is now considered an important part of climate-smart agriculture.

Conclusion

Climate change is a serious challenge for groundnut production because the crop is highly sensitive to temperature rise, drought, rainfall variability, and extreme events. The overall effect is usually negative, even though increased CO2 may provide some limited benefit. Yield response varies across regions, so some locations may face strong losses while others may see smaller changes. The best way to reduce damage is to combine climate-resilient varieties, improved irrigation and moisture conservation, adjusted sowing dates, and locally suitable agronomic practices. In future, crop models, breeding, and climate-smart management will be essential to sustain groundnut productivity under changing climate.

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Natural Farming Pest and Predators Relationship

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Natural farming systems (Fukuoka-style natural farming, Zero Budget Natural Farming, and related agroecological models) avoid synthetic pesticides and rely on biodiversity, soil cover, and on-farm inputs to regulate crop pests. This review synthesizes the ecological theory and published evidence on how pest and natural-enemy populations interact under such systems. It concludes that pest suppression emerges mainly from habitat diversification, reduced disturbance, and the conservation of generalist predators and parasitoids, and less from any single input. Evidence for specific natural-farming preparations remains thin and mostly observational. Priorities for future research include controlled field trials, landscape-scale studies, and long-term monitoring of natural-enemy communities.

1.Introduction

Intensive agriculture has often simplified fields into monocultures with frequent disturbance and heavy chemical input. This tends to suppress natural enemies while favoring fast-reproducing pests, which can trigger pest resurgence and secondary outbreaks. Natural farming takes the opposite approach: it treats the field as an ecosystem in which pests are regulated by the organisms around them (Altieri, 1999; Pretty, 2008).

Natural farming includes Masanobu Fukuoka's no-till, minimal-intervention method (Fukuoka, 1978) and community-scale movements such as Zero Budget Natural Farming (ZBNF) in India (Khadse et al., 2018). Common features are mulching, mixed cropping, and locally made biological inputs. This article asks how these features shape the relationship between herbivorous pests and their predators and parasitoids.

2. Ecological Basis of Pest–Predator Relationships

Enemies hypothesis. Root (1973) found that diverse vegetation supports more predators and parasitoids, and that herbivores are often less abundant there than in simple stands. Later syntheses agree: Letourneau et al. (2011) found that plant diversity generally reduces herbivore numbers and increases natural enemies.

Resource concentration. Monocultures give specialist herbivores a large, easy-to-find food supply. Mixed crops dilute and disrupt that supply.

Generalist predators and alternative prey. Generalist predators such as spiders, ground beetles, and predatory bugs can persist before pests arrive if other prey is available (Symondson et al., 2002). In Indonesian rice, Settle et al. (1996) showed that organic matter supported detritivores and plankton feeders, which sustained generalist predators early in the season and suppressed later planthopper outbreaks.

Plant-mediated signaling. Herbivore-damaged plants release volatiles that attract natural enemies (Kessler & Baldwin, 2001). Chemical disturbance can weaken this signal or the enemies that respond to it.

3. Natural Farming Practices and Their Effects

Mulching and permanent soil cover. Cover and litter give predators shelter, moderate the microclimate, and support detritivore prey. This is the

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main mechanism behind the higher ground-beetle and spider activity commonly reported in low-disturbance systems.

Reduced tillage. Less soil disturbance protects overwintering and ground-dwelling predators and pupating parasitoids.

Polyculture and intercropping. Multiple crop species, including legumes, cereals, and vegetables grown together, offer varied prey, pollen, and nectar. Ratnadass et al. (2012) reviewed how plant diversity helps manage pests and diseases.

Border, trap, and refuge crops. Flowering strips and trap crops (e.g., marigold, maize, or sunflower borders) supply nectar and pollen to parasitoids and hoverflies and can divert pests from the main crop. Landis et al. (2000) list nectar and shelter as key resources for conserving natural enemies.

Push–pull systems. In African maize, intercropping with repellent plants (push) and border trap plants (pull) suppresses stem borers and enhances natural enemies (Khan et al., 2014). It is a well-documented example of the principles natural farming uses.

Fermented and botanical inputs. ZBNF uses preparations such as *Jeevamrutha* and *Beejamrutha* for soil and seed health, and neem-, cow-urine-, and chili-based sprays (*Neemastra*, *Agniastra*, *Brahmastra*) for pests. Botanicals like neem are generally less harmful to natural enemies than broad-spectrum synthetics, but they are not harmless. Their effects depend on formulation, dose, and timing (Isman, 2006). Farmer-reported benefits exist, but replicated field data on these specific preparations are limited.

Habitat for vertebrate predators. Bird perches, hedgerows, and field ponds attract insectivorous birds, frogs, and dragonflies, which add further predation pressure.

4. Key Natural Enemy Groups

Table 1. Major natural-enemy groups, their typical prey, and the practices that support them.

Predator / parasitoid	Typical prey	Supporting practice
Ladybird beetles, lacewings	Aphids, whiteflies, mealybugs	Flowering borders, no broad-spectrum sprays
Spiders, ground beetles	Planthoppers, caterpillars, soil pests	Mulch, reduced tillage
Hoverflies	Aphids	Nectar plants
Trichogramma, *Cotesia*	Borer and caterpillar eggs/larvae	Diverse flowering plants
Predatory bugs (mirids, reduviids)	Planthoppers, caterpillars	Habitat continuity
Birds, frogs, dragonflies	Mixed insects	Perches, ponds, hedgerows

5. Landscape Context

Field-level practices do not act alone. Meta-analyses show that complex landscapes with more non-crop habitat enhance natural enemies and pest control (Bianchi et al., 2006; Chaplin-Kramer et al., 2011), while landscape simplification reduces natural pest control (Rusch et al., 2016). Biological control also depends on the surrounding landscape (Thies & Tscharntke, 1999; Tscharntke et al., 2005). A natural farm surrounded by intensively sprayed monoculture may therefore see lower benefits than one within a diverse mosaic. Coordinated action across neighboring farms, as in community-managed natural farming, may strengthen results.

6. Limitations and Research Gaps

1. **Transition period.** Natural-enemy communities take time to build. Pest

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outbreaks can occur in early seasons before regulation becomes effective.

2. **Not always sufficient.** Some pests, such as invasive species arriving without their natural enemies, may exceed what predators can regulate.
3. **Intraguild predation.** Predators eating other predators can weaken pest suppression in some settings.
4. **Evidence gap.** Most claims about traditional preparations rest on farmer testimony or small trials. Controlled experiments measuring predator abundance, pest density, and yield are needed.
5. **Yield trade-offs.** Some diversified systems show lower yields in certain crops or years, so pest control must be assessed together with productivity and economics (Bommarco et al., 2013).

7. Management Framework

A practical strategy for natural-farming practitioners:

- **Prevent:** diversify crops, rotate, and keep soil covered.
- **Conserve:** provide flowering plants, refuges, and water sources; avoid disrupting predator habitats.
- **Monitor:** scout weekly, count both pests and natural enemies, and act only when pests outpace predators.
- **Intervene gently:** use targeted botanical or mechanical measures as a last resort, and apply them when natural enemies are least exposed.
- **Record:** keep field records to build local evidence.

8. Conclusion

Natural farming shifts pest management from killing pests to sustaining the community that regulates them. Mulching, low disturbance, crop diversity, and habitat features support predator and parasitoid populations that suppress herbivores over time. The ecological principles are well supported by broader agroecological research. Evidence for specific natural-farming inputs is still limited, and results depend on landscape context and the transition period. Rigorous, long-term, multi-site studies are the next step to turn farmer experience into robust science.

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Value Addition in Lakadong Turmeric of North-East India: An Agribusiness Opportunity for Farmer Prosperity

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Turmeric (*Curcuma longa* L.) is one of the most economically important spice crops of North-East India, and among its regional variants, Lakadong turmeric of the Jaintia Hills of Meghalaya stands out for its exceptionally high curcumin content of 7-12 per cent, nearly three to four times that of common commercial varieties. Despite this natural quality advantage and the Geographical Indication (GI) tag conferred in 2024, farmers in the region continue to sell the bulk of their produce as raw or minimally processed rhizome, capturing only a small share of the value realised further down the supply chain. This paper examines the scope for value addition in Lakadong turmeric as an agribusiness strategy, covering primary processing, extraction of curcuminoids and oleoresin, development of consumer-ready nutraceutical and cosmetic products, and the branding and export potential created by the GI status. The recently launched Mission Golden Spice, a five-year Government of India initiative to strengthen the Lakadong turmeric value chain, is discussed as an institutional enabler. The paper concludes that convergence of GI branding, decentralised processing infrastructure, curcumin-extraction facilities, and organised farmer institutions can transform Lakadong turmeric from a subsistence spice crop into a premium agribusiness commodity, substantially raising farm income in the region.

1.Introduction

Agriculture continues to be the primary source of livelihood for a large proportion of the population of North-East India, a region recognised globally as a biodiversity hotspot for spices, fruits and plantation crops. Among the spices grown in the region, turmeric occupies a special position because of the wide genetic diversity of local landraces adapted to the hill agro-climate. While most of the country's turmeric supply originates from Andhra Pradesh, Telangana, Tamil Nadu and Maharashtra, the North-East, and Meghalaya in particular, has emerged as home to one of the finest turmeric variants in the world in terms of curcumin content.

The Lakadong variety, native to the Jaintia Hills region of Meghalaya, is cultivated between roughly 900 and 1,800 metres above sea level under high rainfall, well-drained lateritic soils and largely input-free traditional practices. This unique terroir imparts a curcumin concentration well above the national average, a trait that has attracted the attention of the nutraceutical, pharmaceutical and cosmetic industries. However, despite this inherent advantage, the economic benefit accruing to the primary grower remains limited because the crop is predominantly marketed in raw or lightly cured form. Agribusiness literature consistently identifies value addition, defined broadly as the set of processing, packaging, branding and marketing interventions that enhance the utility and price realisation of a raw commodity, as the most effective lever for correcting this imbalance. This paper therefore examines the current status, opportunities, constraints and policy support available for value addition in Lakadong turmeric, positioning it as a model agribusiness case for spice-based value chains in North-East India more broadly.

2. Production Scenario and Unique Attributes of Lakadong Turmeric

Turmeric cultivation in Meghalaya is concentrated in the West Jaintia Hills, East Jaintia Hills and adjoining

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districts, where smallholder farmers grow the crop largely as a rain-fed, low-input enterprise integrated with shifting or terrace cultivation systems. Field evaluation trials conducted by the ICAR Research Complex for North Eastern Hill Region have documented curcumin content exceeding seven per cent in true Lakadong genotypes, compared with the two to three per cent typically reported for turmeric grown in the major plains-based producing states. Selections and improved clones such as Megha Turmeric-1 have additionally demonstrated higher rhizome yield while retaining much of this curcumin advantage, offering a pathway to combine productivity with quality.

The distinctiveness of Lakadong turmeric was formally recognised in 2024 when it received the Geographical Indication tag from the Geographical Indication Registry, becoming the first turmeric variety in the country to be so recognised and the third product from Meghalaya to receive GI status. The GI tag legally restricts the use of the name to turmeric grown within the defined geographical area, provides a mechanism for quality certification, and creates the legal and marketing foundation on which a premium value chain can be built.

Table 1. Comparative attributes of common turmeric and Lakadong turmeric

Parameter	**Common Turmeric (Andhra Pradesh/Tamil Nadu)**	**Lakadong Turmeric (Meghalaya)**
Curcumin content	2 – 3%	7 – 12%
Colour	Light yellow-orange	Deep orange-red
Cultivation practice	Largely conventional/input-intensive	Traditional, low-input, near-organic
Market status	Commodity spice	GI-tagged (2024), premium niche spice

3. Rationale for Value Addition

The case for value addition in Lakadong turmeric rests on three interlinked arguments. First, the high curcumin content of the raw rhizome is a perishable quality attribute that degrades with poor post-harvest handling; without appropriate curing, drying and grading infrastructure, farmers are unable to fully capture the price premium that the quality justifies. Second, the bulk of the profit margin in spice value chains typically accrues at the processing, branding and retailing stages rather than at the farm gate, so a strategy confined to raw produce sale caps the income potential of the grower regardless of the intrinsic quality of the crop. Third, the GI tag by itself only protects the name; it does not automatically generate a market premium unless it is accompanied by consistent quality standardisation, attractive packaging, traceability, and active promotion, all of which fall within the scope of value addition and agribusiness development rather than primary production.

Value addition therefore needs to be viewed not merely as a post-harvest technical exercise but as an agribusiness strategy that links farm-level production with downstream processing enterprises, marketing institutions and end consumers, thereby distributing a larger share of the final consumer price back to the primary producer.

4. Value-Added Products and Processing Technologies

Value addition in turmeric can be organised along a continuum of increasing technological sophistication and market value, ranging from simple primary processing to high-value extracted and formulated products.

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Primary processing includes harvesting, curing (boiling of fresh rhizomes to gelatinise starch and stabilise colour), sun or mechanical drying, polishing and grading. Improved, low-cost equipment such as manually operated washers, mechanical slicers and hybrid solar-cum-electric dryers developed for hill conditions can substantially reduce drying time, improve hygiene, and preserve curcumin content compared with traditional open-sun drying, which is often associated with contamination and colour loss.

Beyond primary processing, turmeric powder can be further processed into curcumin oleoresin and standardised curcuminoid extracts through solvent extraction, which are the forms demanded by the nutraceutical, pharmaceutical and cosmetic industries. Because Lakadong rhizome already carries a naturally elevated curcumin base, the extraction yield and the resulting product purity are commercially attractive, allowing a price realisation many times higher than that of raw or powdered turmeric.

At the consumer end, a widening range of ready-to-use products can be developed, including turmeric-tea and turmeric-latte premixes, capsules and tablets for the wellness market, turmeric-honey and turmeric-ginger functional blends, and cosmetic lines such as turmeric soap, face packs and skin oils that leverage the crop's traditional use in regional skincare practices. Non-edible avenues such as the use of spent oleoresin cake as a cattle-feed additive or as a natural textile dye further improve overall resource-use efficiency and reduce processing waste.

Table 2. Illustrative value-added product categories from Lakadong turmeric

Product Category	**Examples**	**Primary Market**
Primary processed	Cured/polished rhizome, turmeric powder, turmeric flakes	Domestic retail, spice trade
Extracted bioactives	Curcumin oleoresin, curcuminoid-standardised extracts, essential oil	Nutraceutical, pharma, cosmetic industry
Consumer/ready-to-use	Turmeric tea/latte premix, capsules, tablets, turmeric-honey blends	Health-food, e-commerce, export
Cosmetic & wellness	Turmeric soap, face-pack, skincare oil	Organic/ayurvedic cosmetics segment
By-product utilisation	Spent oleoresin cake as cattle feed additive, natural dye	Livestock, textile-dye niche

5. Agribusiness and Market Potential

The agribusiness potential of Lakadong turmeric extends across domestic and export markets. Domestically, rising consumer awareness of curcumin's antioxidant and anti-inflammatory properties has expanded the market for turmeric-based nutraceuticals, functional foods and organic spices, with premium retail chains and e-commerce platforms increasingly willing to pay a price premium for certified, high-curcumin, GI-tagged produce. Internationally, countries with established herbal and nutraceutical industries represent a growing export opportunity for standardised curcumin extracts and organic turmeric powder, particularly as global demand for natural colourants and plant-based bioactive compounds continues to rise.

For this potential to be realised, agribusiness development needs to proceed along several fronts

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simultaneously: aggregation of smallholder produce through Farmer Producer Organisations (FPOs) and cooperatives to achieve processing scale; establishment of common processing and curcumin-extraction facilities near the production belt to minimise post-harvest losses and transport costs; development of branding, packaging and quality-certification systems that visibly communicate the GI status and curcumin assay to buyers; and forward linkages with pharmaceutical, nutraceutical and cosmetic manufacturers through contract-based supply arrangements. Backward linkages that ensure availability of quality planting material of high-yielding, curcumin-rich clones such as Megha Turmeric-1 are equally important to sustain the raw material base as processing capacity expands.

6. Institutional and Policy Support: Mission Golden Spice

Recognising this potential, the Government of India has launched Mission Golden Spice, an integrated five-year initiative (2025-2030) with an outlay of approximately ₹175.45 crore, aimed specifically at strengthening the Lakadong turmeric value chain in Meghalaya. The mission is being implemented in a convergence mode by the Ministry of Development of North Eastern Region (MDoNER) and the North Eastern Council, with technical and institutional support from agencies including the Spices Board, the National Turmeric Board, ICAR, NABARD and the Small Farmers' Agri-Business Consortium. Its focus areas include expansion of cultivation area, strengthening of Farmer Producer Organisations, creation of integrated curcumin-extraction and processing infrastructure, quality certification, branding under the 'Brand North East' umbrella, and development of export linkages.

Such convergence-based institutional support is significant from an agribusiness standpoint because value addition initiatives led by individual smallholders are rarely viable in isolation given the capital intensity of extraction technology; mission-mode public investment in shared infrastructure and market development can substantially de-risk private and cooperative investment in downstream processing.

7. Constraints and Challenges

Notwithstanding this favourable policy environment, several constraints continue to limit value addition at the farm and enterprise level. Land holdings in the Jaintia Hills are small and fragmented, making it difficult to achieve the volume aggregation required for economical processing. Farm-to-market road and power infrastructure in several producing pockets remains inadequate, raising the cost of transporting perishable fresh rhizome to processing points. Farmers and small entrepreneurs often lack access to affordable credit and modern curing, drying and extraction equipment, and technical knowledge of quality parameters such as curcumin assay and microbial safety standards required by nutraceutical and export buyers is limited at the grassroots level. There is also a risk, documented in other GI-tagged agricultural products, of adulteration or mislabelling of ordinary turmeric as Lakadong turmeric once market demand and price premiums rise, which could erode consumer trust unless a robust traceability and certification mechanism is enforced.

8. Approaches to building sustainable value chains

To overcome these limitations a multi-pronged approach is needed. Farmer Producer Organization strengthening and federation Organizations can help farmers achieve the scale necessary for common processing infrastructure and provide them with more bargaining power in output markets. Decentralized primary processing units at village or cluster level supported by a smaller number of centralized curcumin extraction facilities can balance the need for local employment generation and capital efficiency of larger extraction plants. However, to be able to participate meaningfully in the higher-value segments of the chain rather than be confined to the sale of raw produce, there is need for capacity building of the farmers and rural entrepreneurs in

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post-harvest handling, quality standards and basic business management. A robust, blockchain- or QR-code-based traceability system linked to the GI certification would protect the authenticity of the Lakadong brand and support premium pricing in both domestic and export markets. Finally, active market linkage support, including participation in trade fairs, e-commerce onboarding and facilitation of contracts with nutraceutical and cosmetic manufacturers, is required to convert production and processing capacity into realised sales.

.9. Conclusion

Lakadong turmeric exemplifies how a region-specific quality trait, in this case an exceptionally high curcumin content, can be converted into a distinct agribusiness opportunity when supported by appropriate value addition, branding and institutional development. The Geographical Indication tag secured in 2024 and the subsequent launch of Mission Golden Spice provide an unusually favourable policy window for the region to move beyond raw rhizome trade towards a diversified basket of processed spice powder, curcuminoid extracts, nutraceutical formulations and cosmetic products. Realising this potential fully will depend on strengthening farmer institutions, building shared processing and extraction infrastructure, safeguarding the authenticity of the GI brand through traceability systems, and forging durable linkages with downstream industry. If pursued in a coordinated manner, value addition in Lakadong turmeric can serve as a replicable model for other high-value, geography-specific spice and horticultural products of North-East India, contributing meaningfully to farmer income enhancement and regional agribusiness growth.

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Low Productivity of Forage & Fodder Crops

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Forage and fodder production forms the backbone of livestock health, milk yield, and rural economic sustainability. However, structural deficits, severe land competition, poor certified seed availability, and low technology adoption severely hinder yield potential. This report evaluates the primary drivers of low fodder crop productivity and details strategic, high-impact agronomic interventions—including cereal-legume intercropping, multi-cut perennial cultivars, integrated nutrient management, and advanced preservation techniques—to secure round-the-year forage supply.

Introduction

Forage and fodder availability is a critical determinant of livestock health, milk yield, and farm profitability. Despite its pivotal role in agricultural livelihoods, fodder production faces severe structural deficits, land competition, poor seed availability, and low technology adoption. This report analyzes the primary drivers of low productivity and outlines actionable agronomic interventions to close the supply gap.

Key Metrics:

< 4.5%: Global arable land dedicated to dedicated forage cultivation

35% - 40%: Deficit in green fodder supply during peak lean dry seasons

Target Audience: Agronomists, Dairy Farmers, Policy Makers

Focus Areas: Soil Health, Intercropping, Silage

1. CURRENT CONSTRAINTS IN FODDER PRODUCTION

Constraints & Agronomic Solutions
The persistent gap in quality green and dry forage stems from multiple interconnected constraints across land, seed supply, soil fertility, and water availability.

1.1 Land Allocation and Resource Competition

Low Priority Status: Fodder crops are rarely grown on fertile lands. Food security imperatives prioritize cereal grains and high-value cash crops, forcing fodder onto marginal, degraded soils with poor soil structure and severe organic matter deficits.

Land Fragmentation: Smallholder farmers cultivate tiny plots, making large-scale mechanized forage harvesting and specialized forage management economically unviable.

1.2 Seed Supply & Varietal Bottlenecks

Inadequate Certified Seed Supply: Less than 15% of total fodder seed demand is met by quality certified seed, forcing dependence on low-quality farm-saved seeds.

Dominance of Low-Yielding Varieties: Farmers extensively rely on traditional single-cut landraces that yield low biomass and rapidly turn fibrous, reducing feed digestibility.

High Seed Costs for Hybrids: Superior high-yielding perennial hybrids (e.g., Hybrid Napier) require high initial capital investment and tissue-culture vegetatively propagated cuttings.

1.3 Nutrient & Water Stress Management

Fodder crops are heavy nutrients removers. Repeated harvests of multi-cut fodder crops without adequate

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replenishment deplete soil Nitrogen, Phosphorus, and Zinc. Furthermore, over 70% of fodder area relies on rainfed agriculture, creating acute fodder starvation during summer months.

1.4 Post-Harvest and Conservation Losses

Failure to harvest at the optimum physiological stage (booting/flowering stage) drastically reduces digestible crude protein (CP). Poor preservation leads to massive post-harvest spoilage due to mold, decay, and nutrient leaching.

2. HIGH-IMPACT AGRONOMIC SOLUTIONS

Constraints & Agronomic Solutions
To overcome biomass deficits, integrated agronomic packages must focus on cropping system intensification, soil nutrient management, and adoption of multi-cut cultivars.

2.1 Cereal-Legume Intercropping Systems

Intercropping cereals with leguminous fodder crops maximizes land equivalent ratio (LER) and improves forage crude protein content while lowering synthetic fertilizer requirements.

Sorghum + Cowpea: Sowing Ratio: 2:1 (Row) | Nutritional & Agronomic Benefit: Boosts crude protein to 12-14%; optimizes carbon-nitrogen balance in livestock rumen | Yield Impact: + 28% Green Yield

Maize + Lucerne: Sowing Ratio: 1:1 (Alternate) | Nutritional & Agronomic Benefit: Fixes atmospheric nitrogen (up to 40 kg N/ha); enhances digestible dry matter (DDM) | Yield Impact: + 22% Total Biomass

Pearl Millet + Cluster Bean: Sowing Ratio: 3:1 (Row) | Nutritional & Agronomic Benefit: Exceptional drought resistance; thrives in sandy, low-rainfall arid ecosystems | Yield Impact: + 25% Water Use Efficiency

2.2 Multi-Cut Perennial Cultivars

Transitioning from single-cut to multi-cut perennial crops yields round-the-year green biomass:

Hybrid Napier (Co-4, Co-5, Sampoorna): Provides 6-8 cuts annually yielding over 250 tonnes/ha/year under proper irrigation.

Multi-Cut Sorghum (SSG-59-3): Rapid regrowth capability after cutting, high total soluble sugars, and excellent palatability.

Berseem / Lucerne (Egyptian Clover): Premier winter legume offering 5-6 cuts with high protein (>18% CP).

2.3 Integrated Nutrient & Water Management (INM)

Split Nitrogen Application: Apply 30-40 kg N/ha immediately after each cut to accelerate tillering and vegetative regrowth.

Bio-fertilizers: Seed treatment with Rhizobium (legumes) or Azotobacter (cereals) combined with Phosphate Solubilizing Bacteria (PSB).

Micro-Irrigation: Sprinkler and drip fertigation increase water productivity by 40% and save labor costs.

3. FODDER PRESERVATION & POLICY ROADMAP

Constraints & Agronomic Solutions
Seasonal feed availability follows a feast-or-famine cycle. Post-harvest preservation converts excess monsoon biomass into high-value feed reserves for lean summer months.

3.1 Fodder Preservation Technologies

Silage Making (Controlled Fermentation): Ensilage of succulent crops like Maize and Sorghum at 60-65% moisture under anaerobic conditions converts plant sugars to lactic acid. Silage preserves fodder for over 12 months with minimal loss of beta-carotene and protein.

Haymaking & Block Compaction: Drying leguminous forage (Lucerne, Berseem) down to <15% moisture halts microbial activity. Compacting dry fodder into high-density hay blocks reduces

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storage volume by 70% and enables long-distance transport to drought-hit regions.

3.2 Policy & Action Roadmap for Scaling Fodder Productivity

Short-Term (1-2 Years): Strategic Intervention Area: Seed Banks & Mini-Kits | Key Deliverables: Distribute high-yielding multi-cut fodder mini-kits; establish village seed hubs.

Medium-Term (2-3 Years): Strategic Intervention Area: Silvopastoral Development | Key Deliverables: Plant perennial fodder trees (Subabul, Sesbania) on wasteland borders and field bunds.

Long-Term (3-5 Years): Strategic Intervention Area: Commercial Fodder Markets | Key Deliverables: Form Fodder Producer Organizations (FPOs) and install community silage compaction plants.

CONCLUSION

Fodder must be transitionally managed from a byproduct mindset to an enterprise crop. Coupling intercropping, multi-cut cultivars, integrated fertilization, and year-round silage storage can double livestock forage productivity and significantly enhance rural dairy profitability. Sustainable livestock productivity hinges directly on resolving the systemic supply constraints of quality forage through structured policy enforcement and modern agronomic practices.

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Rabies: A Fatal Disease Transmitted from Dogs to Humans – Prevention is Protection

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Rabies is a viral zoonotic disease that remains one of the most serious preventable causes of death following exposure to an infected animal. Transmission occurs predominantly through the saliva of an infected animal, most commonly following a bite. Scratches or contamination of broken skin or mucous membranes with infectious saliva can also result in exposure. Once clinical disease develops, rabies is almost invariably fatal. Nevertheless, infection can be prevented in exposed individuals through immediate wound care and appropriate post-exposure prophylaxis (PEP) (World Health Organization [WHO], 2024a, 2024b).

The global burden of rabies remains substantial, with approximately 59,000 human deaths estimated to occur annually, particularly in regions of Asia and Africa. Children are especially vulnerable because of their greater likelihood of close interaction with dogs and their increased risk of sustaining bites to the head and neck (WHO, 2024a).

World Rabies Day 2026

World Rabies Day is observed annually on **28 September** to increase public awareness about rabies prevention and encourage coordinated action towards elimination of the disease. Key components of rabies control include vaccination of dogs, prevention of dog bites, prompt wound management, access to PEP and community participation (WHO, 2024a).

The 2026 theme, **"Stronger Together,"** emphasizes the importance of collaboration between communities, veterinary and medical professionals, government agencies, public-health authorities and other stakeholders. World Rabies Day is also associated with the legacy of Louis Pasteur, whose work contributed substantially to the development of rabies vaccination.

Why Is Dog Rabies Important?

Dogs remain the principal source of human rabies transmission globally and are responsible for the overwhelming majority of human rabies deaths. Consequently, controlling rabies infection in dog populations is a central component of strategies aimed at eliminating human dog-mediated rabies (WHO, 2024a).

Rabies virus is transmitted primarily through the saliva of an infected animal. Following a bite, the virus can gain access through damaged skin and subsequently enter peripheral nerves. It then progresses towards the central nervous system, where infection of the brain and spinal cord produces the characteristic neurological disease.

In dogs, rabies may manifest through marked behavioural changes, abnormal aggression or fearfulness, excessive salivation, difficulty swallowing, altered vocalisation, weakness, paralysis and progressive neurological deterioration. However, clinical signs alone cannot establish a definitive diagnosis. Suspected animals should therefore be

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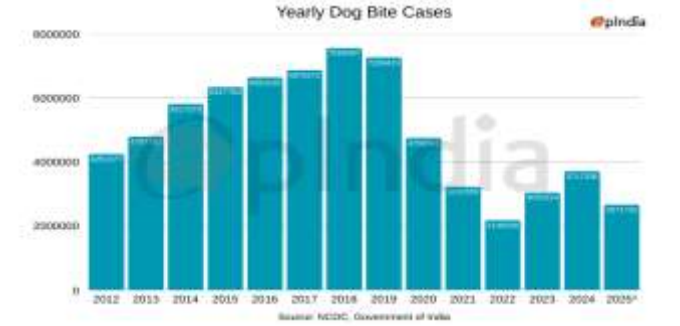
handled only by trained personnel and according to veterinary and public-health procedures.

Current Situation of Rabies in India

Rabies continues to represent an important public-health challenge in India. Estimates reported by WHO from the ICMR–National Institute of Epidemiology indicate approximately **9.1 million animal-bite incidents annually**, with dogs accounting for more than three-quarters of these incidents. The same assessment estimated approximately **5,726 human deaths from rabies annually** in India (WHO, 2024b).



These figures demonstrate that rabies prevention requires sustained intervention rather than isolated responses to individual bite incidents. Because rabies involves interactions among humans, animals and their shared environment, its control is appropriately addressed through a **One Health approach**. Veterinary services, human-health services, local authorities, public-health agencies and communities therefore have complementary responsibilities in rabies prevention and elimination.

Human Rabies: Why Immediate Action Matters

Following exposure, the incubation period of rabies is variable and may extend from several weeks to months. The duration can be influenced by factors such as the site and severity of exposure and the distance between the exposure site and the central nervous system.

Early illness may include fever, headache, weakness, malaise and abnormal sensations such as pain, tingling or itching at the site of exposure. With progression of neurological disease, affected individuals may develop anxiety, agitation, confusion, abnormal behaviour, difficulty swallowing, hydrophobia, aerophobia, paralysis, coma and ultimately death.

Because clinical rabies has an extremely poor prognosis, **post-exposure intervention must not be delayed until symptoms develop**. Every potentially significant exposure should be assessed promptly by an appropriately trained healthcare professional (WHO, 2024a, 2018b).

What Should You Do Immediately After a Dog Bite?

1. Wash the wound immediately

The wound should be washed and flushed thoroughly with soap and running water for approximately **15 minutes**. Immediate and thorough wound cleansing is an important component of rabies post-exposure management (WHO, 2018a, 2018b).

2. Seek medical attention promptly

After washing the wound, the exposed person should seek medical attention without delay. A healthcare professional should assess the nature of the exposure and determine whether PEP is required.

3. Receive rabies vaccine when indicated

Rabies vaccines used for PEP are highly effective when administered appropriately. The vaccination regimen should be selected according to the exposure category and the applicable national or WHO recommendations (WHO, 2018b).

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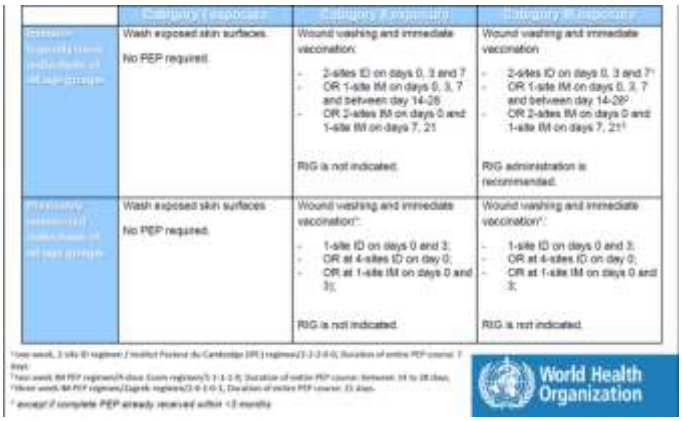
4. Rabies immunoglobulin when indicated

For severe exposures, particularly category III exposures, rabies immunoglobulin may be indicated in addition to vaccination. When required, it should be administered appropriately into and around the wound according to established clinical guidance (WHO, 2018a, 2018b).

A seemingly minor wound should not be used as a reason to dismiss the possibility of rabies exposure. Similarly, the fact that the biting animal is a household pet does not by itself eliminate the need for professional risk assessment.



Dog Vaccination: The Key to Prevention

Vaccinating dogs is a fundamental component of efforts to eliminate dog-mediated human rabies. Effective programmes require sustained vaccination coverage of dog populations in combination with access to PEP, disease surveillance, responsible dog ownership and appropriate management of dog populations (WHO, 2024a).

WHO has emphasized the importance of maintaining approximately **70% vaccination coverage in dog populations** to interrupt transmission at the population level. Consequently, vaccination programmes should reach both owned and free-roaming dogs rather than concentrating exclusively on household pets (WHO, 2024a).

Management of Free-Roaming Dog Populations

Dog vaccination needs to be integrated with other measures rather than implemented as an isolated intervention. Depending on local circumstances, comprehensive rabies-control programmes may include scientifically appropriate dog-population management, Animal Birth Control (ABC) programmes, responsible ownership, improved waste management and community education aimed at reducing dog-bite risk.

Long-term rabies control requires sustained surveillance, vaccination and population-management measures. Community engagement is particularly important because human behaviour, dog ownership practices, waste disposal and interactions between people and free-roaming dogs can influence exposure risk.

Rabies Control Policies and Programmes in India

India has implemented the **National Rabies Control Programme (NRCP)** to strengthen activities related to animal-bite management, human rabies surveillance, training, laboratory capacity, public awareness and community participation (Ministry of Health and Family Welfare, Government of India, n.d.).

India has also adopted the **National Action Plan for Dog Mediated Rabies Elimination (NAPRE)**, which aims to eliminate dog-mediated human rabies as a public-health problem by **2030**. The plan adopts a One Health framework and emphasizes mass dog vaccination, appropriate PEP, surveillance and coordination among relevant sectors (Government of India, 2021).

Implementation of these programmes requires coordination among animal-husbandry and veterinary services, health departments, municipal and panchayat authorities, public-health agencies, medical and veterinary professionals and local communities.

Role of Veterinarians, Doctors and Local Bodies

Rabies elimination requires coordinated action across multiple sectors.

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Veterinarians have important responsibilities in vaccination of dogs, recognition and management of suspected animal cases, animal-health surveillance, communication with animal owners and participation in community rabies-control programmes. Medical professionals are responsible for appropriate wound management, assessment of exposure risk and administration of PEP and rabies immunoglobulin when indicated.

Local authorities contribute through implementation of dog-vaccination programmes, scientifically appropriate dog-population management, environmental sanitation and community-level awareness activities.

The veterinary profession therefore has a significant role in the One Health response to rabies—not only through treatment and vaccination of animals but also through surveillance, public education and coordination with human-health services.

Important Messages for Farmers and Dog Owners

- Vaccinate pet dogs according to the schedule recommended by a veterinarian and applicable veterinary authorities.
- Maintain responsible control of dogs and avoid unnecessary free roaming.
- Teach children to avoid approaching unfamiliar dogs without adult supervision.
- Do not attempt to handle animals displaying abnormal behaviour without professional guidance.
- Following a potentially risky bite or scratch, immediately wash the wound with soap and running water and seek medical attention.
- Avoid applying substances such as chilli, turmeric, oil, mud or plant preparations to bite wounds.
- Do not handle or kill a suspected rabid animal unnecessarily. Inform the appropriate veterinary or public-health authority and follow official instructions.
- Avoid direct contact with animals suspected of rabies.

Prevention Is Better Than Cure

Rabies presents a critical paradox: **it is preventable before clinical disease develops, but clinical rabies is almost invariably fatal**. Consequently, prevention must operate at both animal and human levels.

Sustained vaccination of dogs, responsible ownership, appropriate management of free-roaming dog populations, improved waste management, prevention of dog bites, public education, early wound washing and timely access to PEP are complementary components of rabies prevention (WHO, 2018a, 2018b, 2024a).

Conclusion

Rabies remains a preventable but potentially fatal zoonotic disease. Reducing its impact requires more than responding to individual bite incidents. Sustained dog vaccination, responsible dog ownership, appropriate dog-population management, community education, effective surveillance and timely PEP are all essential components of a comprehensive control strategy.

India's goal of eliminating dog-mediated human rabies requires continued collaboration among veterinary services, medical professionals, government agencies, local authorities and communities. A coordinated One Health approach can strengthen prevention efforts and contribute to achieving the national elimination objective.

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Beyond Orange: Unlocking the Genetic and Nutritional Diversity of Carrot

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Carrot (*Daucus carota* L.) is one of the most familiar root vegetables in the world, commonly recognized by its bright orange colour. However, the biological diversity of carrot extends far beyond orange roots. Carrot germplasm includes **orange, purple, black, red, yellow and white roots**, each representing different combinations of pigments, phytochemicals and genetic backgrounds. This diversity makes carrot an important crop not only for vegetable production but also for **nutritional improvement, functional foods and modern plant breeding**. The nutritional characteristics of carrot are strongly influenced by genotype. Studies have demonstrated variation among carrot cultivars in carotenoids, phenolic compounds, anthocyanins, vitamins and antioxidant capacity. Therefore, the colour of a carrot can provide an initial visual indication of underlying biochemical diversity, although colour alone cannot fully describe its nutritional composition.

A Rainbow Beneath the Soil

The familiar orange carrot is rich in carotenoids, particularly **α-carotene and β-carotene**. β-carotene is nutritionally important because it can be converted by the human body into vitamin A. Purple and black carrots, in contrast, are characterized by the accumulation of **anthocyanins**, while yellow carrots possess distinctive carotenoid profiles. Red carrots may contain different combinations of carotenoids, including lycopene in particular genetic backgrounds. White carrots generally contain relatively low levels of coloured carotenoids.\Consequently, carrot colour represents more than an aesthetic trait—it reflects underlying biochemical and genetic variation.

Table 1. Colour diversity and major nutritional characteristics of carrot

Root colour	Major associated compounds	Breeding/nutritional significance
Orange	α-carotene, β-carotene and other carotenoids	Important source of provitamin-A carotenoids
Purple/black	Anthocyanins, phenolic compounds	Potential source of antioxidant phytochemicals and natural colourants
Red	Carotenoids; lycopene in some genetic backgrounds	Provides additional pigment and phytochemical diversity
Yellow	Xanthophylls and other carotenoids	Useful source of diverse carotenoid profiles
White	Lower coloured-pigment concentration; other phytochemicals	Valuable genetic material for studying pigment pathways

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Source: Synthesized from Arscott and Tanumihardjo (2010), Nicolle et al. (2004), and Iorizzo et al. (2020).

Colour diversity and major nutritional characteristics of carrot

Figure 1- Colour diversity and major nutritional characteristics of carrot.

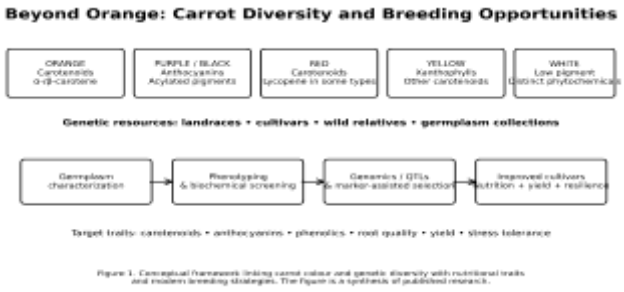

Figure 1. Conceptual framework linking carrot colour and genetic diversity with nutritional traits and modern breeding strategies. The figure is an original synthesis based on published research.

Genetic Diversity: The Raw Material of Breeding

Genetic diversity is the foundation of crop improvement. In carrot, variation occurs for numerous economically and nutritionally important traits, including **root colour, shape, length, diameter, weight, carotenoid concentration, anthocyanin content, maturity, flavour, disease response and environmental adaptation**. The domestication history of carrot has involved selection for root characteristics and other desirable traits. Transcriptome-based research comparing cultivated and wild carrots identified thousands of single-nucleotide polymorphisms and genes showing evidence of selection, demonstrating the genetic complexity underlying carrot domestication. For breeders, this diversity provides opportunities to combine favourable alleles from different genetic backgrounds rather than relying solely on existing commercial cultivars.

Orange Carrot: A Natural Source of Provitamin A

Orange carrots owe their characteristic colour primarily to the accumulation of carotenoids. Among these, **β-carotene and α-carotene** are particularly important because they possess provitamin-A activity. Historical breeding efforts have successfully increased provitamin-A carotenoid concentrations in carrot. This demonstrates that nutritional composition can be treated as a breeding objective alongside yield, shape and market quality. The availability of the carrot genome has further improved understanding of the molecular mechanisms controlling carotenoid accumulation. The chromosome-scale carrot genome identified gene families associated with pigment accumulation and provided an important foundation for genomics-assisted breeding.

Purple and Black Carrots: The Anthocyanin Treasure

Purple and black carrots are particularly valuable because their colour is associated with **anthocyanin accumulation**. Anthocyanins are water-soluble flavonoid pigments that contribute to the red, purple and blue colours of many plants. Research has shown considerable variation among purple carrot germplasm for both **total anthocyanin concentration and pigment composition**. The relative proportions of acylated and non-acylated anthocyanins can also differ among genetic stocks. Such differences are important because pigment structure can influence stability and potential application as a natural food colourant. Importantly, anthocyanin pigmentation is genetically complex. Molecular studies have identified numerous loci and QTLs associated with anthocyanin accumulation in

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carrot. This information can assist breeders in developing cultivars with predictable pigment characteristics.

Nutritional Quality Is Controlled by Both Genes and Environment

Carrot nutritional quality is not determined by genetics alone. **Genotype × environment interactions, mineral nutrition, maturity and production conditions** can influence the concentration of bioactive compounds. For example, research evaluating different carrot cultivars demonstrated that both genetic background and mineral supply influenced carotenoids, vitamin C, phenolic acids and antioxidant capacity. This indicates that nutritional improvement should integrate **genotype selection with appropriate crop management**.

Table 2. Major breeding targets for next-generation carrot cultivars

Target	Important traits	Potential breeding strategy
Nutritional enhancement	β-carotene, α-carotene, anthocyanins	Germplasm screening and marker-assisted selection
Root productivity	Root weight, diameter, length and marketable yield	Conventional selection and genomic selection
Colour diversity	Orange, purple, red, yellow and white	Phenotypic selection and pigment profiling
Functional-food potential	Anthocyanins, carotenoids and phenolics	Biochemical screening
Climate resilience	Heat, drought and disease tolerance	Stress screening + molecular breeding
Consumer acceptance	Flavour, texture, shape and uniformity	Multi-trait selection

The Genome Is Changing Carrot Breeding

The publication of a high-quality carrot genome assembly marked an important milestone in carrot genetics. Genome information has provided researchers with opportunities to investigate the genetic basis of pigmentation, root development, flavour, flowering and stress responses. Modern carrot improvement can now combine conventional breeding with: Molecular markers, Quantitative trait locus (QTL) analysis, Genome-wide association studies, Transcriptomics, High-throughput phenotyping, Genomic selection, Candidate-gene analysis, Genome editing. These technologies can shorten the path from identifying useful genetic variation to incorporating it into improved breeding populations. Reviews of carrot research indicate that genomics and high-throughput sequencing are increasingly contributing to nutritional studies, resistance breeding and cultivar development.

From Germplasm to Functional Carrot

The future of carrot breeding is likely to involve **multi-trait improvement** rather than selection for yield alone. A successful cultivar should ideally combine high productivity with nutritional quality, attractive appearance, desirable flavour, storage ability and adaptation to local environments. For example, a breeding programme could aim to develop an orange carrot with enhanced provitamin-A carotenoids while maintaining good root shape and yield. Another programme could target purple carrots with high concentrations of stable anthocyanins for

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fresh consumption or natural food-colour applications.

Such approaches transform carrot from a conventional vegetable into a potential **functional-food crop**.

Table 3. Conventional versus modern approaches in carrot improvement

Feature	Conventional breeding	Modern breeding
Selection basis	Visible phenotype	Phenotype + molecular information
Nutritional traits	Laboratory screening	High-throughput biochemical and genomic screening
Genetic information	Limited	Genome-wide information
QTL identification	Difficult and time-consuming	Marker-based identification
Selection efficiency	Depends strongly on phenotype	Can use markers linked with target traits
Potential for precision	Moderate	Higher
Major advantage	Simple and established	Efficient exploitation of complex genetic variation

Conservation of Carrot Diversity: An Essential Investment

Genetic improvement cannot progress without genetic resources. Wild relatives, traditional varieties, landraces and older cultivars may contain alleles that are absent or rare in modern commercial populations. Conservation of carrot germplasm therefore serves two purposes. First, it protects biodiversity for future generations. Second, it provides breeders with a reservoir of genetic variation for addressing emerging challenges such as climate stress, new diseases, changing consumer preferences and nutritional security.

The study of carrot domestication has already demonstrated the value of comparing cultivated and wild genetic resources to understand the evolutionary changes that shaped the crop.

What Lies Beyond Orange?

The future of carrot is not simply about producing more roots—it is about producing **better and more diverse roots**. The combination of conventional breeding, nutritional profiling and molecular genetics offers an opportunity to develop cultivars tailored for specific nutritional and agricultural purposes. Imagine carrots bred specifically for:

High provitamin A → improved nutritional value
High anthocyanin → functional-food and natural-colour applications
High carotenoid diversity → broader phytochemical profiles
Climate resilience → stable production under environmental stress
Superior root quality → better consumer acceptance and market value

Conclusion

Carrot is a striking example of how genetic diversity can translate into nutritional diversity. The familiar orange root represents only one part of the crop's biological spectrum. Purple, black, red, yellow and white carrots contain different combinations of

pigments and phytochemicals, providing valuable resources for both nutrition and breeding. The integration of germplasm conservation, phenotypic evaluation, biochemical screening, genomics and molecular breeding can accelerate the development of carrots with improved nutritional value, productivity and resilience. The carrot of the future may therefore be defined not by a single colour, but by a portfolio of traits designed to meet the nutritional and agricultural needs of a changing world. Beyond orange lies an entire spectrum of genetic possibilities—and that spectrum may hold the key to the next generation of nutritionally enhanced carrots.

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Caesalpinia bonduc: Medicinal Significance, Nutraceutical Prospects and Sustainable Utilization

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Caesalpinia bonduc (L.) Roxb. commonly called as bonduc nut which is currently recognized as *Guilandia bonduc* L., is an underutilized medicinal and multipurpose plant belonging to the family Fabaceae. It is a thorny creeper like shrub widely distributed in tropical and subtropical regions. The seeds and other parts of the plants are traditionally valued for its medicinal uses and are associated with ethnobotanical importance. Phytochemical investigations have reported the presence of various bioactive compounds including flavonoids, terpenoids, diterpenoids, steroids, and other secondary metabolites. Despite its traditional importance and phytochemical richness, the species remains poorly explored for systemic cultivation, value addition and commercial utilization. Similarly, conservation of natural populations is important for safeguard its genetic diversity and traditional knowledge. The present study highlights the botanical characters, traditional and phytochemical importance, nutraceutical potential, ecological significance, commercial prospects associated with *Caeasalpinia bonduc.*

Introduction

Medicinal plants have been closely associated with human life from ancient times. Many plant species that growing in forest, wastelands, coastal areas and village landscapes have been used by local communities for generations. However, several of these traditional important plant species remains underutilized and insufficiently explored. One such promising species is *Caesalpinia bonduc* (L.) Roxb., a thorny medicinal plant with considerable nutritional, ecological and commercial potential (Srinivasan *et al.,* 2024 and Lokonon *et al.,* 2021). The plant is known by different regional names and has attracted scientific attention because of its traditional uses and the presence of several biologically active compounds. With the increasing interest in medicinal plants, nutraceuticals and the sustainable utilization of biological resources, *C. bonduc* deserves greater attention from researchers, farmers and conservationists.

Taxonomy, Morphology and Distribution

Caesalpinia bonduc belongs to the family Fabaceae. It is generally woody, large, scrambling or climbing shrub armed with strong prickles. Its prickly stems and fruits give the plant a distinctive appearance. The leaves are compound and consist of several small leaflets while the plant produces attractive yellow flowers. The fruits are covered with prickles and contain hard, smooth, greyish seeds, which are among the most recognizable features (Srinivasan *et al.,* 2024). The plant is adapted to tropical and subtropical environments. It's likely found in India, Srilanka, Andaman & Nicobar Island and can grow under relatively harsh conditions. Hardy nature and distinctive morphology of the plant make it an interesting species from ecological and conservation prospective. The species has also attracted scientific attention because of its traditional uses and potential importance as an underutilized medicinal plant. Older publications frequently refer the species as *Caesalpinia bonducella*, whereas the modern taxonomic literature recognized it as

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Guilandina bonduc L (Gagnon *et al.,* 2016 and Srinivasan *et al.,* 2024). The plant is commonly called as bonduc, bonduc nut, fever nut, physic nut, nicker nut, yellow nicker and grey nicker. In India, it is known by different vernacular names in different regions, such as Kazharchikai (Tamil), Gachakaya (Telugu), Katkaranj (Hindi), Latakaranja (Sanskrit), Kazhanchikkuru (Malayalam), Gajaga (Kannada), Nata (Bengali), Sagargota (Marathi). Vernacular names vary from region to region but the scientific name remains the most reliable means of identification.

Ethnomedicinal and Phytochemical Attribute

For generations, different part of *C. bonduc*, particularly its seeds, leaves and roots have been used in various traditional systems of medicine. This traditional knowledge has encouraged scientist to investigate the plant, its chemical constituents and its biological properties (Lokonon *et al.,* 2021and Srinivasan *et al.,* 2024). Scientific studies have reported the presence of several group of phytochemcials, including phenolic compounds, flavonoids, terpenoids-related compounds and other secondary metaboloites (Srinivasan *et al.,* 2024 and Zanin *et al.,* 2012 and Do Nascimento & David, 2024). These natural constituents have contributed to the growing scientific interest in *C. bonduc* and its potential for the development of plant-based products. Traditional use and promising laboratory findings alone do not establish the safety or therapeutic efficacy of the plant or its derived products in humans. Further rigorous studies are required to establish its safety, optimal dosage, and therapeutic efficacy. Such research can help distinguish promising possibilities from scientifically established applications and support the responsible development and utilization of *C. bonduc* (Srinivasan *et al.,* 2024).

Therapeutical Significance

The growing popularity and demand for natural and plant-based products has created increasing interest in nutraceuticals. Nutraceuticals are broadly understood as a food or natural product based substances that may provide health benefits and have potential commercial applications. The presence of various bioactive compounds in *C. bonduc* has attracted interest in its potential for future nutraceutical research. Studies have investigated its phytochemcial constituents and reported biological activities including antioxidant, antidiabetic, anti-inflammatory, anticancer, antifertility, antimalarial and antimicrobial properties (Srinivasan *et al.,* 2024 and Zanin *et al.,* 2012 and Do Nascimento & David, 2024 and Sasidharan *et al*., 2019). However, the presence of bioactive compounds and promising laboratory findings alone are not sufficient to establish a plant as a nutraceutical product also appropriate quality standards, safety assessment, dosage determination and scientific validation are essential for developing the medicinal or nutraceutical product (Srinivasan *et al.,* 2024). Thus, *C. bonduc* should currently be considered a promising research for nutraceutical resource rather than an established nutraceutical product.

Environment Role and Conservation

Apart from its medicinal importance, *C. bonduc* also has ecological values. Like other wild medicinal plants it forms part of natural ecosystem and contributes to plant biodiversity. Wild plant species are valuable reservoirs of genetic resources and may possess useful traits that could support future research and the development of plant-based resources. They also help maintain traditional knowledge associated with local plant resources (Lokonon *et al.,* 2021 and Srinivasan *et al.,* 2024). In addition, *C. bonduc* also have greater ecological importance through its association with nitrogen-fixing microorganisms in this soil. Such interactions may contribute to nutrient cycling and support in nutrient-poor environments. The species is also adapted to sandy coastal habitats, where its growth may help stabilize loose soil and sand (Wouyou *et al*., 2022). However, habitat destruction and

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indiscriminate collection can negatively affect wild plant populations. Therefore, the conservation of natural habitats and sustainable utilization of medicinal plants are important for maintain these valuable resources. Conservation efforts should also consider local knowledge and the role of local communities in the sustainable use of plant resources. *C. bonduc*, proper conservation and sustainable harvesting can help maintain its availability for future generations (Lokonon *et al.,* 2021).

Economical Value and Utilization

The growing demand for herbal medicines, cosmetics and natural products is creating new interest in underutilized plant species. This trend may provide opportunities for the sustainable utilization and value addition of medicinal plants. *C. bonduc* has potential for further exploration in plant nurseries, nutraceutical research, personal-care products, and small-scale rural enterprises. The diverse phytochemical composition and longstanding traditional uses of the species have attracted considerable scientific interest in recent years. (Srinivasan *et al.,* 2024 and Do Nascimento & David, 2024). However, commercial development of *C. bonduc* should be based on scientific evidence, proper quality control, safety assessment and sustainable sourcing. Cultivation rather than excessive collection from natural populations could provide a more sustainable source of raw material. In the long term, the development of suitable cultivation, processing and value addition technologies has enlightened the opportunities for farmers and rural communities. Such approaches could help connect biodiversity conservation with responsible commercial utilization of the species (Lokonon *et al.,* 2021).

Conclusion

Caesalpinia bonduc is more than a thorny wild shrub. It is an underutilized plant resource with promising medicinal, nutraceutical, ecological and commercial potential. Its traditional importance and diverse phytochemical constituents have generated considerable scientific interest, eventhough *C. bonduc* comes under least concern category in IUCN red list, due to its over exploitation for the above said needs, conservation plays a major role for sustainable utilization of this species. *C. bonduc* viewed as a promising resource for further research and sustainable development rather than as an established medicinal or nutraceutical product. Conservation, scientific cultivation, quality evaluation and responsible value addition could help unlock its potential. With appropriate research and sustainable utilization, this underexplored plant may contribute to biodiversity conservation, rural development and the responsible use of natural resources.

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Meta analysis of growth parameter in nutrient management for blackgram

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The field experiment was conducted during Zaid season of 2022 at the Crop Research Farm, Department of Agronomy, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj (U.P.) India. To study the Influence of Growth Regulators on the growth of Black gram. The treatments consist of levels of Gibberellic Acid (GA_3 – 15 ppm, GA_3 – 30 ppm, GA_3 – 45 ppm) and Salicylic acid (SA – 50 ppm, SA – 75 ppm, SA – 100 ppm). The soil of experimental plot was sandy loamy in texture, nearly neutral in soil reaction (pH 7.8), low in organic carbon (0.35%). Results revealed that application of GA3 45 ppm + 50 ppm Salicylic acid (T_{10}) recorded with plant height (40.08 cm), plant dry weight (7.13 g/plant), were also recorded in treatment T_{10} GA3 45 ppm + 100 ppm Salicylic acid at 15 & 40 DAS. Integrated nutrient management on growth parameters of black gram under field conditions, during (kharif) season of 2017. The research was conducted with nine treatments, in which one control, 100% recommended dose of fertilizer alone and seven treatments with combination of organic and inorganic fertilizers i.e. farm yard manure 5 t ha^{-1}, vermicompost 2.5 t ha^{-1},poultry manure 2.5t ha^{-1} ,nitrogen 5 kg ha^{-1} and phosphorus 11 kg ha^{-1} respectively and Rhizobium along with biofertilizer as used for seed treatment. Observations were recorded on growth parameters such as plant height (cm), number of leaves $plant^{-1}$ and number of branches $plant^{-1}$. An application of 100% recommended dose of fertilizer gave maximum plant height (51.37 cm) at 85 DAS (days after sowing), number of leaves (26.60) $plant^{-1}$ and branches $plant^{-1}$ 14.00 at 60 DAS in treatment T_1 as compared to others. Among the different grain legumes, blackgram is a well-known leguminous crop A field experiment was conducted during *Autumn* season of 2018 and 2019, to evaluate the effect of humic acid (HA) application on growth of blackgram The treatments were: Control (sowing of dry seed) (T_1); Seed priming (soaking) in water (T_2); Seed priming in 0.5% humic acid solution (T_3); Seed priming in 1% humic acid solution (T_4); Seed priming in 2% Humic acid solution (T_5); Soil application of humic acid @1 kg/ha (T_6); Soil application of humic acid @ 2 kg/ha (T_7); Soil application of humic acid @1 kg/ha + 10 t compost/ha (T_8); Soil application of humic acid @ 2 kg/ha + 10 t compost/ha (T_9); Foliar application of 0.01% humic acid solution 25 days after sowing (DAS) (T_{10}); Foliar application of 0.05% humic acid solution (25 DAS) (T_{11}); Foliar application of 0.1% humic acid solution (25 DAS) (T_{12}).Soil application of humic acid along with compost had significant on growth of blackgram treatment was obtained from the treatment T_9 and the second-best treatment was T_8.

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Introduction

Black gram is the most important legume crop and India alone produce more than two-third of the world‟s production (Saini and Jaiwal, 2002) as food, feed and industrial raw material and ranks as the third important pulse crop in India (Selvakumar *et al.*, 2012). Total black gram production was 3280 thousand tonnes; of which percentage share in 13.48% during 2017-18 (Anonymous, 2018). Due to its wider adaptability, it is grown across a wide range of agro-ecological zones. In Punjab, cultivation is about 1.1 million tons of mash every single year from about 2.2 thousand hectares of area with an average productivity of 539 kg per hectare in 2015- 2016. Black gram considered as a staple food for about 900 million consumers and about one third of all underfed children. After green revolution cereal grain production increased, which resulted in sharp decline of per capita production and availability of pulses with record of 4.0 million tonnes of imported pulses in 2012-13 (Singh *et al*., 2017). The term pulse refers as the dried seed/grain. In India major pulse crops grown are chickpea, pigeonpea, mung bean, urd bean and lentil etc. These are highly nutritious, rich in dietary fiber, sugar and almost contains no fats (Kokani *et al*., 2014).

Leguminosae is the family that includes blackgram. The significant pulse crop grown throughout India's various agro-climatic zones is black gram. Although this crop is farmed during the Kharif and Rabi seasons, the majority of its land is planted during the former, when intercropping with crops like sorghum, pearl millet, maize, cotton, castor, and pigeon pea is highly common. In terms of India's main pulse crops, black gram holds a significant position (Fatima Anaya *et al*..2015, Ferdowsi noor *et al*.,2017, Vekaria *et al*.,2017). A complete array of nutrients, including 20 to 25% protein, 40 to 47% starch, ash lipids, carbs, and important vitamins, may be found in black gramme (Neelambari *et al*.,2018, Nikita Nehal *et al.,2018,* Pradip Kumar Saini *et al.,* 2017). In 2012–2013, the total area, production, and productivity of black gramme in India were 3.11 million hectares, 1.90 million tonnes, and 611 kg/ha, respectively (Anonymous *et a*l., 2018). A vast class of tetracyclic diterpenoid plant growth agents is known as the gibberellins. In order to control plant growth, GA_3 acts as a hormone, and this knowledge dates back to the 1950s (Solanki Mital *et al*., 2017). Salicylic acid, also known as orthohydroxybenzoic acid, is a secondary metabolite that functions similarly to chemicals that control development. important in increasing the crop's growth (Reham Dawar *et al*., 2020). Its ranked third among all pulses in India and contributes to 10% of the national pulse production from an area of 13% of total pulse crop area. Blackgram is rich in nutrients such as protein (25-28%), oil (1-1.5%), carbohydrate (60-65%), essential mineral (K, Ca, Zn), various vitamins (Vit C, B), fibre (3.5-4.5%) and antioxidant compounds that can help to boost the human health (Lavanya *et al*., 2022 and Patial *et al*., 2022). It is also rich in amino acids like methionine, cysteine and lysine. Both production and area under this crop lay decreased during last decade. The targeted production and productivity are possible by way of harnessing the yield gap by growing pulses in new niches *i.e*., precision farming, quality inputs, soil test based integrated nutrient management and mechanized method of pulse cultivation complimented with generous governmental policies and appropriate funding support to implementing stake holders. Maintenance of soil organic material at a satisfactory level is needed for sustainable and high productivity of crops over long periods (Govindasamy, 2002). Humic acid (HA) is the major component of most of the organic fertilizers and the most active components of soil and organic matter might help to overcome these production constraints in the pulse crops. Humic substances arise from chemical and biological degradation of plant and animal residues and from synthetic activities of micro-organisms (Schnitzer, 1968). It enriches the soil and facilitates fertilizer nutrients to reach their maximum potential in improving plant growth (Nithila *et al*.,2013).

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Discussion

Plant Height

At 60 DAS, the significantly higher plant height of (40.08 cm) was recorded with treatment-10 (GA_3 45 ppm + 100 ppm salicylic acid at 15 & 40 DAS). However, T_9 GA_3 45 ppm + 75 ppm salicylic acid at 15 & 40 DAS (39.34cm) was found to be statistically at par with T_{10} (GA_3 45 ppm + 100 ppm salicylic acid at 15 & 40 DAS). The plant height of Black Gram increased significantly due to with at Harvest, Foliar application of GA3 significantly influenced the black gram plant height (cm).Similar results were reported by Rehem Dawar *et al*. (2020). According to Singh (2008), an improvement in the soil's nutrient status and the creation of a conducive environment for better root growth through the secretion of growth promoting substances like Gibberellin, cytokinin, and auxin are responsible for the significant increase in the number of pods per plant following seed inoculation with growth regulators.

Plant height is an important index of plant growth at a given time during the growth period. it is revealed that the plant height has positive respond to different humic acid application doses and methods. Soil application of humic acid @ 2 kg ha^{-1} along with farm compost @ 10 t ha^{-1} (T_9) recorded higher plant height (*i.e*., 45.62 cm) in 2018 and also in 2019 (51.07 cm). However, the minimum plant height was observed in T_1 in 2019 but in 2018, T_2 (receiving N-P-K fertilizers plus seed priming was done with plain water) shows minimum plant height. The plant height was significantly influenced by soil application of humic acid along with compost during both the years.

Soil application and foliar spray of humic acid (HA) significantly increased plant height over other seed treatment and control where no humic acid applied and there is no significant difference between seed priming with control in both the year of experiment. Plant height was recorded more at higher dose of HA at soil with compost. However, seed priming with higher doses of HA (2%) in some cases shows better result than the seed priming with lower doses of HA. The positive effect of humic acid in improving plant height was probably due to synergistic and beneficial effect due to the adequate nutrient availability thus resulted in greater elongation (Singeravel *et al*., 1993). The increased plant height can also justify by Prasad and Prasad (1994) that auxin derivatives are involved in cell division and differentiation also expansion through increasing the plasticity thereby enhancing growth and development.

The effect of integrated nutrient management on recommended dose of fertilizer, farm yard manure, vermi-compost and poultry manure on growth habits of black gram. Thus the results were depicted the following heads. Plant height (cm) of black gram was recorded at three different intervals (30, 60 and 85 DAS) and the influence of organic and inorganic sources .The plant height observations recorded at 30, 60 and 85 DAS were significantly different among the treatments. The maximum plant height at 30 DAS was recorded in T_1 (22.55 cm) followed by T_4 (21.91 cm), T_3 (21.87 cm), T_6 (20.66 cm), T_2 (19.38 cm), T_7 (18.79 cm) and T_8 (18.77 cm), while the minimum plant height was observed inT_5 (18.30 cm). At 60 DAS the maximum plant height was also recorded in T_1 (34.47 cm) which was statistically at par with T_4 (33.27 cm) and the minimum plant height was recorded in T_0 (25.13 cm). Similarly, the maximum plant height at the time of harvest (85 DAS) was recorded in T_1 (51.37 cm) and the minimum height was recorded in T_0 (43.87 cm). The maximum increased in plant height was observed in those plots treated with 100 % RDF and 75 % RDF + 25 % vermi-compost. The possible reason for this could be because the growing pattern and increased seed rate that allows the plant to avoid inter plant competition for nutrients (Rathore *et al*., 2010). Sufficient amount of nutrients from the inorganic fertilizers as well as some from the organic fertilizers improves the cell activities, cell multiplication and luxuriant growth of the plant which could explained the increased in plant height of the crop (Fashina *et*

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al., 2002). The reduction in the nitrogen at an early growing stage could reduce the rate of photosynthesis which could attribute in the reduction of plant height. Similar findings were also reported by Singh *et al*., (2011).

Number of Leaves

The effect of integrated nutrient management on number of leaves of black gram were found to have no significant difference amongst the treatments at 30, 60 and 85 DAS at the time of harvest At 30 DAS the maximum number of leaves were observed in T_1 (11.53) followed by T_4 (11.20). At 60 DAS the minimum number of leaves were recorded in T_5 (21.13) which was lower by T_1 (26.60) and T_4 (26.60) which were the maximum number of leaves recorded. At the time of harvest (85 DAS), the maximum number of leaves were recorded in T_2 (19.33) which was higher than control T_0 (17.00). The increased in number of leaves per plant were either observed in plots treated with 100 % RDF or plots treated with combination of organic and inorganic fertilizers. Application of fertilizers solely or in combined form improves the soil fertility level as well as nutrients which enables better root development and root nodules allowing the plant to take up the nutrients with ease which might be the reason for increase in the number of leaves (Rathore *et al*., 2010). Similar finding was also reported by Vadgave (2010).

Number of branches

Branches number plant^{-1} The statistical analysis at an initial stage (30 DAS) revealed that number of branches per plant were found to have no significant difference amongst the treatments but when comparisons were made T_1 (3.67) and T_4 (3.33) were higher than T_0 (2.00) and T_8 (2.00). At 60 DAS the treatments were significantly different between all the treatments and the maximum numbers of branches were observed in T_1 (14.00) followed by T_4 (13.67) which were both higher than control i.e., T_0 (8.00). Reddy *et al*., (2011) reported that the increased in number of branches could be possible because the application of organic and inorganic fertilizers along with biofertilizers due to enhancement of microbial activity in the rhizosphere which enables the roots for the better uptake of nutrients. Similarly, the application of organic and inorganic fertilizers increases the overall growth attributes of the crop due to their synergistic effect Singh *et al*., (2008; 2011).

Leaf area index (LAI)

Leaf area Index (LAI), an important growth factor of blackgram crop and data regarding LAI are shown in Humic acid treatment adapted in blackgram crop has significant effect on its LAI in both the year of experiments. It is clear that in comparison to other treatments the highest LAI (3.38 and 3.52 respectively in 2018 and 2019) was obtained from T_9 treatment. However, both the control (T_1 and T_2) treatment gives the lower value of LAI in both the year of experiments. The combine effect of HA and compost improved the LAI significantly. Most of the growth stages seed priming was at par with the control and the two control treatments (T_1 and T_2) were at par in both the years. Higher LAI values might be due to adequate supply of nitrogen that had produced larger leaves and reflected in more photosynthetic area coupled with the increased growth rate, respiration rate and metabolic activity due to humic substances (Saravanan *et al*., 1989).

Dry aerial biomass

Dry aerial biomass is one of the most important parameters and has a marked influenced on final growth realization of a crop. The mean dry aerial biomass of blackgram as influenced by different treatments of humic acid , Soil application of HA with or without compost had a profound effect in increasing the total aerial dry matter production over control and treatments receiving N-P-K and seed priming (T_2). T_9 treatment recorded the highest value of dry aerial biomass in both the years of experiments where HA at 2 kg ha^{-1} was applied in soil along with farm compost at 10t ha^{-1}; the second highest value of

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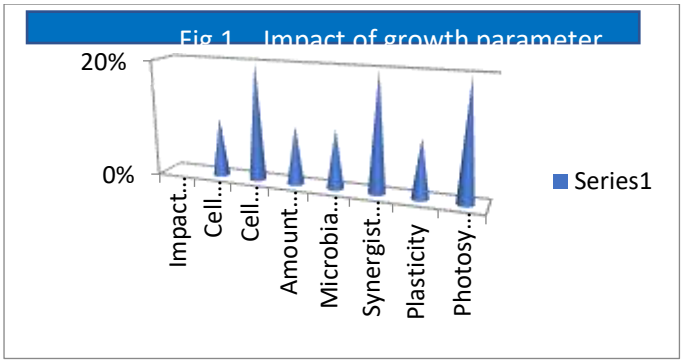
dry aerial biomass was recorded in treatment T_8 where HA at 1 kg ha^{-1} was applied in soil along with farm compost at 10 t ha^{-1} and the lowest value was recorded in control treatment (T_1). The revealed that foliar application of HA significantly increased the dry aerial biomass over in both 2018 and 2019 and on an average, there was an increase of 37.86 and 37.18% over control in 2018 and 2019, respectively. The results of this experiment are similar with the finding of Khazaie *et al*., (2011). HA was capable of increasing the total amount of dry weight in soybean, peanut and clover plants (Tan *et al*., 1983).



Conclusion

Summary and Conclusion is as follows the growth parameters of black gram i.e. plant height, leaves number $plant^{-1}$, branches number $plant^{-1}$ was significantly varied with different treatments. It was also reported that all growth parameters significantly increased with the increasing doses 100% with RDF. Amongst all the treatments 100% of RDF gave maximum plant growth as compared to other treatments at different growth intervals, While, it was at par with application of 75% RDF + 25% vermi-compost. It was also reported that during these studies the recommended dosage of fertilizer gave significantly higher in plant height (T_1 100% RDF at harvest 34.47 cm), leaves number $plant^{-1}$ 26.60 at 60 DAS and branch number $plant^{-1}$ 14.00 over control when compared to other treatments.

HA is one of the active major present in organic fertilizer as well as soil and organic matter. This study established that application of humic acids increased overall crop performance and productivity of blackgram. Among the different methods, soil application of humic acid was found to be the best, particularly when applied with compost. Therefore, soil application of humic acid @ 2 kg ha^{-1} + 10 t compost ha^{-1} (T_9) might be the best option for increasing productivity and quality of blackgram. It was concluded that with the application of GA3 45 ppm along with 50 ppm Salicylic acid at 15 & 40 DAS T_{10}, has performs positively and improves growth parameters.

From the Meta analysis growth is influenced (Fig.1.,) by cell activities, cell multiplication, amount of fertilizer, Microbial activity, synergistic effect, plasticity and photosynthesis. Here 20% level influenced and compared to these each three factors cell multiplication, Synergistic effect and photosynthesis. Other factors each one 10% impact to provide for growth parameters development in blackgram .

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CRIJAF Sona: A Microbial Breakthrough in Jute Retting Technology

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Traditional jute retting the process of biologically separating fibre from the plant's woody core remains slow, water intensive and inconsistent, typically requiring 20-25 days and yielding variable fibre quality that limits farmer income and increases India's dependence on imported fibre. To address this, the ICAR-Central Research Institute for Jute and Allied Fibres (CRIJAF), Barrackpore, has developed a microbial consortium, CRIJAF Sona, comprising selected bacterial and fungal strains that accelerate pectin breakdown when applied to submerged jute bundles. Field application shortens the retting period to just 10-12 days, improves fibre grade by up to two levels, and raises productivity by 8-10%, enabling farmers to earn an additional ₹12,000-15,000 per hectare for a modest input cost of ₹1,200-1,500. The formulation is environmentally safe, has a six month shelf life and has been successfully adopted across West Bengal, Assam, Bihar, Odisha, Meghalaya and Uttar Pradesh. By improving fibre quality and reducing retting time and water dependency, CRIJAF Sona offers a scalable, economically viable solution to enhance both farmer profitability and the competitiveness of India's jute industry.

Introduction

Jute, long celebrated as India's "Golden Fibre," has for generation's sustained rural economies across West Bengal, Assam, Bihar, and Odisha, where millions of smallholder farmers depend on the crop for their livelihood. As the world's largest producer of raw jute, India relies on the crop to support an entire value chain of cultivators, retting workers, mill labourers, and traders across the eastern Gangetic plains. Yet the traditional retting process by which fibre is biologically separated from the plant's woody core has changed little over the decades. Conventional retting involves submerging bundled jute stalks in ponds or slow-moving water for three to four weeks, allowing naturally occurring microorganisms to break down the pectin binding fibre to stem. This uncontrolled, nature-dependent method brings persistent drawbacks: lengthy processing times, inconsistent fibre quality that fetches lower prices, and heavy reliance on clean water sources that are growing scarcer and more polluted. These constraints have limited farmer incomes and forced Indian jute mills to import higher-grade fibre from abroad an added cost for an industry that should, in principle, be self-sufficient. It is against this backdrop that the ICAR-Central Research Institute for Jute and Allied Fibres (CRIJAF), Barrackpore, Kolkata, has developed an innovative microbial consortium named "CRIJAF Sona" a formulation designed to accelerate and improve retting at its biological core. More than an incremental fix, it represents a breakthrough with the potential to reshape the economics of jute cultivation, offering farmers a faster, more profitable path from

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field to fibre while easing pressure on India's water resources.

Problems associated with traditional retting process:

Conventional jute retting is a slow, water intensive process in which harvested stalks are bundled and submerged in ponds, ditches or slow flowing water bodies for three to four weeks. Over this period, naturally occurring microorganisms break down the pectin and other binding substances that hold the fibre to the plant's woody core. Effective as this method is in principle, its uncontrolled, nature dependent character brings with it several persistent drawbacks:

- ✓ Extended duration of 20-25 days or more, delaying farmers' access to market ready produce
- ✓ Inconsistent fibre quality, often yielding lower grades that fetch reduced prices
- ✓ Dependence on clean water sources, which are growing scarcer amid environmental degradation and competing agricultural demands
- ✓ Greater reliance on imported fibre by domestic jute mills, as indigenous fibre often falls short of the lustre and strength required for high value products

Together, these challenges have constrained the profitability of jute farming and placed added strain on India's jute processing industry, which has long had to import superior quality, glossy and strong fibre at considerable cost.

Science behind CRIJAF Sona:

CRIJAF Sona is a scientifically formulated microbial powder comprising selected bacterial and fungal strains that accelerate and enhance the natural retting process. When applied to bundled jute stalks locally known as "jaak", submerged in water, the consortium works synergistically to break down the pectinaceous bonds far more efficiently than the ambient microbial population alone. This targeted biological intervention enables faster, more uniform fibre separation while preserving and in many cases improving, the intrinsic strength and lustre of the fibre. Importantly, extensive testing has confirmed that the formulation is environmentally benign, posing no adverse effects on fish, aquatic life, crops, livestock or human health a critical consideration given that retting typically takes place in shared water bodies used for irrigation, fishing, and household purposes.

Key benefits for farmers and industry:

The adoption of CRIJAF Sona offers a compelling value proposition across the entire jute value chain:

1. Dramatically Reduced Retting Time:

The retting period is shortened to just 12-15 days, compared to the 25-30 days required under traditional methods, a reduction of nearly 70%. This enables farmers to bring their produce to market sooner and frees up water bodies and land for subsequent agricultural use.

2. Increased Productivity:

The shortened retting duration translates directly into an 8-10% increase in overall fibre productivity, as reduced exposure time minimizes the fibre loss and degradation that often accompany prolonged traditional retting.

3. Superior Fibre Quality:

Fibre retted using CRIJAF Sona shows an improvement of up to two full grades over conventionally retted fibre. Higher grade fibre commands significantly better prices in the market and reduces the industry's reliance on costly imported alternatives.

4. Attractive Return on Investment:

For an additional investment of just ₹1,200 to ₹1,500 per hectare, farmers can realize incremental earnings of ₹12,000 to ₹15,000 per hectare, a remarkable

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return that makes adoption financially compelling even for smallholder farmers.

5. Extended Shelf Life and Flexibility:

The microbial mixture carries a shelf life of six months, giving farmers the flexibility to purchase and store the product in advance and apply it according to their own harvest and retting schedules.

6. User and Environment Friendly:

The product is safe for repeated handling and poses no harm to the aquatic ecosystems in which retting takes place, aligning its use with sustainable agricultural practice.

Method of Application:

Achieving the best results with CRIJAF Sona depends on a few key environmental conditions. The retting water should ideally be clean, slow moving and low in salinity fast currents can disperse the microbial consortium before it takes effect, while stagnant or contaminated water can introduce competing organisms that interfere with the process. Ponds, canals and gently flowing streams that are otherwise used for conventional retting are generally well suited for the treatment, provided they are not heavily silted or polluted. The application process itself is straightforward, requiring no specialized equipment or technical training, which makes it readily accessible to farmers accustomed to traditional retting practices. Harvested jute stalks are first bundled into compact sheaves locally known as "jaak" and fully submerged in water, weighted down as needed to ensure complete immersion. The CRIJAF Sona powder is then applied directly onto and around the submerged bundles, typically dissolved or dispersed into the surrounding water to ensure even contact with the stalks. Once introduced, the microbial consortium begins acting almost immediately, colonizing the stalk surface and initiating accelerated breakdown of the pectin layer that binds the fibre to the woody core. Unlike the gradual, inconsistent action of ambient microorganisms in traditional retting, this targeted microbial activity proceeds uniformly across the bundle, loosening the fibre within approximately six to seven days less than a third of the time required by conventional methods. Farmers can then extract, wash, and dry the fibre using standard post retting practices, with no additional processing steps required.

To further extend the technology's reach beyond research trials and pilot demonstrations, CRIJAF has also developed a commercialized version of the formulation, marketed under the name "CRIJAF Sena." This commercial variant is designed for easier distribution through agricultural input dealers and farmer cooperatives, helping bridge the gap between laboratory innovation and on-the-ground adoption across India's jute growing belt.

Geographic Reach and Adoption:

What began as a solution tailored primarily to West Bengal's jute belt has since expanded well beyond the state's borders. CRIJAF Sona has been successfully adopted in major jute producing regions including Assam, Bihar, Odisha, Meghalaya and Uttar Pradesh, while trials have likewise shown encouraging productivity gains. This widespread geographic uptake underscores the technology's adaptability

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across diverse agro climatic conditions and water resource profiles.

Economic and Industrial Significance:

Beyond its direct benefits to individual farmers, CRIJAF Sona carries broader implications for India's jute industry as a whole. By enabling domestic production of higher grade, more lustrous, and stronger fibre, the technology has the potential to reduce the jute sector's dependence on costly fibre imports thereby strengthening the competitiveness of Indian jute mills and advancing the "Atmanirbhar Bharat" (self-reliant India) vision within the natural fibre sector. Additionally, the shortened retting cycle eases pressure on water bodies during peak agricultural seasons, an increasingly important consideration amid growing concerns over water scarcity and quality in rural India.

Cost and Accessibility:

Affordability lies at the heart of CRIJAF Sona's appeal and it is a factor that has clearly shaped the product's design and pricing. A single packet, priced at approximately ₹1,200, is sufficient to treat jute cultivated over one hectare, a cost that, while representing a genuine upfront outlay for resource constrained farmers, is quickly offset by the technology's returns. As outlined earlier, this modest investment translates into incremental earnings of ₹12,000 to ₹15,000 per hectare through improved fibre grade and productivity, yielding a benefit-to-cost ratio that few agricultural inputs can match. This pricing structure is particularly significant given the demographic profile of India's jute growing community, which is overwhelmingly composed of small and marginal farmers cultivating modest landholdings, often under tight cash flow constraints between harvest cycles. A single hectare packet size keeps the entry cost low and the decision to adopt straightforward, without requiring farmers to make large upfront commitments or purchase in bulk. Combined with the product's six month shelf life, this also allows farmers to plan purchases around their own financial cycles buying ahead during periods of surplus income and applying the formulation when the harvest is ready, rather than being tied to a narrow window of availability.

Taken together, these features position CRIJAF Sona not merely as a technically superior alternative to traditional retting, but as an economically viable one, a rare combination that is often the deciding factor in whether an agricultural innovation moves from research station to farmers' fields at scale.

Conclusion

CRIJAF Sona represents a compelling example of how targeted agricultural biotechnology can address deep rooted, decades old challenges in traditional retting practices. By compressing retting time, improving fibre grade, boosting farmer income and reducing environmental and resource burdens, this microbial innovation offers a scalable, sustainable pathway forward for India's jute sector. As adoption continues to spread across states and awareness grows through extension programs and commercialized formulations like CRIJAF Sena, CRIJAF Sona stands poised to play a defining role in revitalizing the Golden Fibre economy for the next generation of Indian farmers.

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Candidate Plus Tree Selection: A Critical Approach for Genetic Improvement in Forestry

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India's forests cover approximately 21.71% of the total geographical area (India State of Forest Report, 2023), yet their productivity remains critically low at 1.34 cubic metres per hectare per year against a world average of 2.1 m^3/ha/year. Candidate Plus Tree (CPT) selection is the foundational step in any tree improvement programme, aiming to identify genetically superior individuals from natural stands and plantations for use as parents in breeding and seed orchard programmes. A plus tree is distinguished by phenotypic superiority in commercially important traits such as height, girth at breast height, clear bole height, stem straightness, crown architecture, branching habit, and resistance to pests and diseases. Selection methods vary with stand type- The Comparison Tree Method and Total Score Method are preferred for even-aged plantations, while the Regression Method, Mother Tree System, Subjective Grading, and Base Line Selection are employed in uneven-aged or mixed species forests. Identified CPTs are systematically evaluated through convergence of quantifiable and scored traits into a weighted score, and confirmed plus trees are marked with yellow or red paint bands and geo-tagged for long-term monitoring. Standard Operating Procedures of ICFRE provide an evidence-based, replicable framework covering major timber species. Robust CPT selection accelerates genetic gain, widens the seed orchard base, and is indispensable for meeting India's growing wood demand sustainably.

1.Introduction

Forests are vital for ecological balance and rural livelihoods. In India, forests cover about 21.71% of the geographical area, while per capita forest availability remains low at 0.064 ha compared with the global average of 0.64 ha (FSI, 2023; FAO). Low forest productivity, coupled with increasing demand for timber, pulpwood and non-timber forest products, has further widened the gap between forest resource supply and demand.

Tree improvement through systematic genetic selection offers one of the most cost-effective strategies to bridge this productivity gap. At the heart of every tree improvement programme lies the selection of genetically superior individuals — universally termed 'plus trees' or 'Candidate Plus Trees (CPTs)'. A plus tree is an individual that phenotypically surpasses its neighbours in one or more economically important traits and is selected as a parent for breeding or seed orchard programmes (Zobel and Talbert, 1984). Forest research institutes come under Indian council of Forestry Research and Education has formulated comprehensive Standard Operating Procedures (SOPs) for plus tree selection, providing a standardized, replicable framework for forest officers and field staff across India.

This article reviews the concept, criteria, methods, and significance of Candidate Plus Tree selection, drawing primarily from the ICFRE SOPs (2023) and supporting literature, to underscore its pivotal role in sustainable forest genetic improvement.

2. What is a Candidate Plus Tree (CPT)?

A Candidate Plus Tree (CPT) is defined as a tree that has been tentatively selected based on its desirable phenotypic qualities but has not yet undergone genetic testing (ICFRE, 2023). Once a CPT is verified through progeny testing and confirmed to possess heritable superiority, it is designated as a 'Plus Tree'. The distinction is important: phenotypic

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superiority does not always guarantee genotypic excellence because environmental factors can mask the true breeding value of an individual.

The process of plus tree selection is anchored in the principle that genetic gain in a breeding programme cannot exceed the genetic quality of the parents used. As Zobel and Talbert (1984) succinctly stated "The gains can be no greater than the quality of the parents used." Therefore, rigorous and systematic selection of CPTs is the indispensable first step before any genetic testing, seed orchard establishment, or advanced breeding work.

Table 1. Key distinctions between a Candidate Plus Tree and a confirmed Plus Tree

Feature	Candidate Plus Tree (CPT)	Confirmed Plus Tree
Basis of selection	Phenotypic superiority	Phenotypic + progeny-tested genotypic superiority
Genetic testing	Not yet conducted	Conducted and validated
Use in programme	Potential parent; scion collection	Seed orchard parent; advanced breeding
Marking	Yellow/red paint band	Registered in breeding population

3. Importance of Candidate Plus Tree Selection in Tree Improvement

Selection is universally acknowledged as the first and most consequential step in any tree improvement programme. Its importance in forest trees is even more pronounced than in annual crops for several reasons rooted in the unique biology of trees (ICFRE, 2023; Zobel and Talbert, 1984)

- **Longevity and Environmental Exposure:** Trees live for decades or centuries, during which they are exposed to diverse environmental pressures pest outbreaks, drought, storm damage, and disease epidemics. Selected CPTs must demonstrate resilience to these stressors so that their progeny can withstand similar pressures over long rotations.
- **Extended Generation Interval:** Unlike field crops with annual generations, forest trees have generation intervals of several years to decades. Early selection of superior individuals minimises the time lost in advancing a breeding programme, thereby maximising genetic gain per unit time.
- **Foundation of Genetic Gain:** Selection determines the maximum possible genetic improvement. Any tree improvement programme whether aimed at increasing volume production, improving wood quality, or enhancing disease resistance can only achieve results commensurate with the quality of parents selected.
- **Seed Orchard Establishment:** CPTs serve as the source of grafts and cuttings for establishing clonal seed orchards. The genetic composition of the seed orchard, and hence the quality of improved planting material produced, is directly determined by the quality of CPTs selected.
- **Broad Genetic Base:** Selection from across a wide geographic range ensures that the breeding population captures sufficient genetic diversity for adaptation to changing environments and future breeding cycles.
- **Economic Returns:** Improved planting material derived from rigorously selected CPTs has been shown to deliver 15–25% higher yields in timber volume compared to unimproved seedlots, translating directly into

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enhanced livelihoods for forest-dependent communities and better return on investment for afforestation programmes.

4. Desired Characters for Candidate Plus Tree Selection

Selection criteria vary depending on the commercial objective timber, fruit, fodder, or non-timber forest products.

4.1 Timber Species and/or Species Valued for Bark

For timber-yielding species such as Shorea robusta (Sal), Tectona grandis (Teak), Terminalia alata (Asana), and Pterocarpus marsupium (Bija Sal), the following characters are prioritized

Table 2. Desired characters for timber species CPT selection

Character	Desired Condition
Stem form	Straight, cylindrical, non-forking, non-twisting bole
Cross-section	Circular with minimal taper
Clear bole height	Long (minimum 4/5 of total height preferred)
Crown architecture	Small, compact crown; good natural pruning
Branch angle	75°–90° to main stem (flat angled); thin branches
Bark grain	Absence of spiral grain
Age criteria	More than half the rotation age
Health status	Free from pests and diseases (≤0% infection preferred)
Vigour	Superior height (at least 5% above average) and DBH (20% above average)
Flowering/fruiting	Moderate to good production

4.2 Fruit, Fodder and NTFP Species

For species valued for their fruit, seed, leaf, or other non-timber products such as Terminalia chebula (Harida/Harad), Phyllanthus emblica (Amla), Syzygium cumini (Jamun), Madhuca indica (Mahua), and Pongamia pinnata (Karanja) emphasis shifts to canopy and yield traits

- Large, wide crown with dense, healthy foliage
- Prolific and regular flowering and fruiting (>90% crown coverage in flowering preferred)
- High fruit/seed yield per tree in terms of weight and number
- Desirable fruit quality parameters: fruit size, pulp weight, seed weight, oil content
- Disease and pest resistance, especially freedom from fungal and insect damage
- Vigorous growth superior height and girth compared to surrounding trees
- Age: more than half the rotation age, but not over-mature

5. Methods of Candidate Plus Tree Selection

The choice of selection method is governed by stand structure, species ecology, availability of comparison trees, and the objectives of the breeding programme. There are two major groups based on stand type.

5.1 Selection in Even-Aged Stands and Plantations

Even-aged stands and plantations are the preferred environments for CPT selection because trees of the same age and spacing can be directly compared

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without confounding effects of age or competition.
Four principal methods are applicable

Table 3. Comparison of CPT selection methods for even-aged stands

Method	Principle	Advantage	Limitation
Comparison Tree Method (Point Grading)	CPT compared against 5 best neighbouring trees within 25–100 m	Corrects for local environmental effects; objective	Less useful in uneven-aged/mixed stands
Total Score Method (Selection Index)	All traits weighted and summed into a composite index score	Most efficient; compensates weakness in one trait with strength in another	Requires heritability and economic weight data; index must be revised periodically
Independent Culling Method	Minimum standards set for each trait; rejection if any trait falls below threshold	Simple; ensures no critical trait is ignored	May eliminate trees with exceptional overall value; complicated with many traits
Selection Indices Method	Multiple regression-based index combining genetic and economic weights	Scientifically most rigorous	Requires extensive genetic data; rarely used in initial field selection

5.2 Selection in Uneven-Aged, Mixed Species or Sprout-Origin Stands

Many Indian forests are structurally complex: trees vary widely in age, species composition is mixed, and direct comparison between individuals is difficult. For such conditions, four alternative methods are recommended

- **Regression Selection Method:** A regression line relating volume (or height) to age is developed from measurements of at least 50 representative trees. A candidate falling above this line by a defined distance is accepted. This is the most robust method for uneven-aged stands but requires prior data collection.
- **Mother Tree System:** Superior 'good' trees are identified and seed collected from them for progeny testing; the best parents are then used in vegetative seed orchards. This method has a longer lead time but is valuable for hardwood species where planting programmes are small and seeds are not urgently needed.
- **Subjective Grading System:** Experienced foresters evaluate candidates visually based on standardised criteria. Reliable only when undertaken by trained personnel with well-defined grading protocols to minimise inter-observer variation.
- **Base Line Selection Method:** An average (baseline) value for each trait is established from 20–25 dominant and co-dominant trees

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in the stand. Candidates exceeding the baseline by a defined margin for traits under strong genetic control (stem straightness, branching habit, disease resistance) are selected as CPTs.

6. Data Collection and Screening Process

Once a CPT is tentatively identified in the field, comprehensive data is recorded using standardised datasheets (ICFRE, 2023). Data are categorised into quantifiable traits measured in the field and scored traits assessed visually.

6.1 Quantifiable Traits

The following measurements are taken using standard dendro-mensurational instruments (measuring tape, calipers, Ravi altimeter, laser hypsometer):

- **Total Height (m):** Straight-line distance from ground level to the tip of the leading shoot; measured using the single-pole method, clinometer, or laser hypsometer.
- **Clear Bole Height (CBH, m):** Distance from the base of the tree to the first living branch forming part of the crown.
- **Girth at Breast Height (GBH, m):** Circumference of the stem at 1.37 m above ground level on the uphill side; converted to DBH for standardisation.
- **Crown Height (m):** Vertical distance from ground level to the midpoint between the lowest green branch and the uppermost branches.
- **Crown Width (m):** Average horizontal diameter of the crown, measured using the shadow method or direct measurement in two perpendicular directions.
- **Number of Primary Branches:** Count of branches arising directly from the main trunk.

6.2 Scored Traits (Visual Assessment)

Qualitative traits are evaluated on a standardised scale, typically 0–10, with descriptors for each score

Table 4. Scoring criteria for qualitative traits (ICFRE, 2023)

Trait	Score 10 (Best)	Score 8	Score 6 (Minimum Acceptable)
Stem Straightness	>4/5 of total height perfectly straight	>3/5 of total height straight	2.5/5 to 3/5 of height straight
Stem Circularity	Circular cross-section, minimal taper	Moderately circular, low taper	Moderately circular, higher taper
Branch Angle	75°–90° to main stem	60°–75°	45°–60°
Disease/Pest Status	Nil infection	<10% infection (slight)	10–20% infection (moderate)
Crown Density (fruiting spp.)	Dense foliage	Moderately dense	Less dense but acceptable
Flowering (fruiting spp.)	>90% crown flowering	75–90%	60–75%

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6.3 Convergence, Weighting and Final Screening

Since quantifiable measurements are in different units (metres, centimetres) while scored traits are already on a 0–10 scale, all data must first be standardised to a common scale. This is achieved either by dividing the data range into five class intervals (each assigned a score of 6, 7, 8, 9, or 10) or by computing superiority ratios relative to comparison tree averages.

Once all traits are on the same scale, a weighted score is computed for each CPT. Weightage is allocated according to the commercial objective of selection

- **For timber species:** greater weight to GBH (2.0), clear bole height (2.0), stem straightness (1.5), and stem form (1.5); lesser weight to crown attributes.
- **For fruit/fodder/NTFP species:** greater weight to crown width (1.5), crown height (1.75), number of branches (1.75), and fruiting/flowering intensity.

A CPT whose final weighted score exceeds the population average is confirmed and physically marked in the field. The marking protocol specifies yellow or red paint bands of 5 cm width applied at 5 cm above and below breast height (1.37 m), with the CPT identification code written between the bands in the format: Division/Range/Genus-Species/Serial Number (e.g., KO/BA/PS-01 for Pterocarpus marsupium no. 1, Baripada Range, Koraput Division). Geographic coordinates are recorded using GPS, and increasingly, geotagging is employed for permanent location records (ICFRE, 2023).

7. Key Precautions in Candidate Plus Tree Selection

Systematic selection is prone to errors that can compromise the genetic integrity of the breeding programme. The ICFRE SOPs (2023) enumerate the following critical precautions, which align with international best practices (Zobel and Talbert, 1984; Sidhu, 1996)

- Selection effort must be concentrated on good to average stands; isolated trees or border trees in a stand must be excluded as they have had an unfair competitive advantage.
- Age of candidate trees must exceed half the rotation age of the species but must not surpass the rotation age to avoid selecting over-mature individuals with declining vigour.
- No more than 3–4 selections per hectare are recommended to preserve broad genetic diversity and reduce the risk of selecting close relatives.
- Stands that have been high-graded (logged selectively for the best trees) must be avoided, as they have already lost their genetically superior individuals.
- Selection should span the maximum possible geographic range of the species' distribution (typically 30–40 trees) to ensure broad genetic representation.
- Candidate trees should be at least 5% superior in height and 20% superior in diameter at breast height over the average of comparison trees.
- Traits of economic significance must be ranked in descending order of priority before selection begins; this prevents subjective drift during field evaluation.
- At least 1 km aerial distance should be maintained between selected CPTs from the same stand to reduce the probability of selecting close relatives or inbred individuals.

Role of CPT Selection in National Forest Improvement Programmes

India's National Afforestation Programme and the Rashtriya Krishi Vikas Yojana Agroforestry component both emphasise the supply of Quality Planting Material (QPM) as a cornerstone of their

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objectives (Ministry of Agriculture and Farmers Welfare, 2023). CPT selection directly feeds into this mandate: CPTs serve as the foundation for clonal orchards, certified seed stands, and progeny trial networks, which collectively produce the improved, genetically verified planting stock needed for large-scale afforestation, farm forestry, and agroforestry schemes.

The Forest Research Institutes which comes under ICFRE maintain active CPT databases and seed orchards for priority timber, NTFP, and agroforestry species. State Forest Departments in Odisha, Chhattisgarh, Haryana, and Tamil Nadu have operationalised ICFRE's SOPs to systematically expand their CPT registries, enabling a cascading improvement in the quality of planting material available to forest divisions and farmers alike.

Conclusion

Candidate Plus Tree selection is not merely a technical forestry operation it is the genetic cornerstone upon which all downstream tree improvement activities rest. The systematic identification, evaluation, and marking of phenotypically superior individuals using evidence-based, standardised protocols which ensures that the genetic potential of India's forest species is captured, conserved, and channelled into improved planting material. Given India's urgent need to bridge the massive gap between domestic timber and NTFP demand and supply, and in the context of meeting national climate commitments through enhanced forest carbon stocks, CPT selection programmes deserve prioritised investment, field staff capacity-building, and integration with modern tools such as GPS geo-tagging, drone-assisted stand assessment, and DNA marker-based parentage verification. Trees are the longest-lived organisms that most human generations will interact with. Selecting the right parents today is a gift to future forests, future ecosystems, and future communities.

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Mechanizatation Challenges In Modern Crop Production

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1. Introduction

Agricultural mechanization means the use of machines, tools and equipment in diffffferentagricultural operations. It includes land preparation, sowing, planting, irrigation, weeding,harvrvesting and post-harvrvesting operations. Modern crop production depends on mechanizationto complete farm operations at the right time and with less human labour.Mechanization helps farmers to save time and labour, increase effffficiency and improve cropproduction. However, several challenges limit the adoption of agricultural machinery, especially among small and marginal farmers.

1. High Cost of Farm Machinery

The initial cost of modern agricultural machinery is very high. Tractors, harvrvesters, seed drills,transplanters and other machines require a large investment. Small and marginal farmers maynot have enough money to purchase such equipment.The cost of fuel, maintenance, repair and spare parts also increases the total cost ofmechanized farming. Therefofore, expensive machinery is one of the majajor challenges in moderncrop production.

2. Small and Fragmented Land Holdings

Many farmers own small and scattered pieces of land. Large agricultural machines requiresufffficient space fofor effffficient operation. Small and irregular fields make it diffffficult to operatetractors, harvrvesters and other large machines.Fragmented land holdings also increase the time required fofor transporting and operatingmachinery. Therefofore, machinery designed fofor small farms is necessary.

3. Lack of Skilled LabourModern agricultural

machines require skilled operators. Farmers need proper knowledge tooperate tractors, harvrvesters, planters and other equipment safely and effffficiently.In many rural areas, trained machine operators are not easily available. Lack of skilled labourcan lead to improper operation, machine damage and reduced effffficiency.

4. Lack of TeTechnical

Farmers may not have sufffficient technical knowledge about modern agricultural machinery.They may not know which machine is suitable fofor a particular crop, soil type or farmingoperation.Proper knowledge is also necessary fofor machine adjustment, operation and maintenance.Training and demonstrations can help farmers understand the correct use of machinery.

5. High Maintenance and Repair Cost Agricultural

machines require regular maintenance and servrvicing. Replacement of damagedparts and repair of machines can be expensive.If machinery is not maintained properly, its perfrfoformance decreases and the machine may breakdown during important farm operations. This can cause delays in sowing, harvrvesting and otheractivities.

6. Lack of Credit Facilities

Many farmers cannot purchase modern machinery because of limited financial resources.Agricultural machinery requires a large amount of investment, which may not be possible fromfarm income alone.Easy and affffofordable credit facilities can

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help farmers purchase or hire suitable agriculturalmachinery. Financial support is especially important fofor small and marginal farmers.

7. High Fuel and Energy Cost Most agricultural

machines such as tractors and harvrvesters depend on fuel. Increasing fuelprices increase the operating cost of farm machinery.High fuel consumption can reduce the economic benefits of mechanization. Therefofore,fuel-effffficient machines and alternative energy sources can help reduce operating expenses.

8. Lack of Suitable Machinery

A single type of machine cannot be used effffficiently fofor every crop and farming condition.Diffffferent crops require diffffferent machines fofor sowing, planting, harvrvesting and processing.Suitable machinery may not be available fofor certain crops, soil types and small farms.Development of affffofordable and crop-specific machinery is therefofore important.

9. Lack of Repair and Servrvice Facilities

Proper repair and servrvice centres are essential fofor maintaining agricultural machinery. In somerural areas, these facilities may be far away or unavailable.Farmers may have to transport damaged machines over long distances fofor repair. Thisincreases repair expenses and causes delays in farm operations.

10. Diffffficult Field Conditions

Diffffferent agricultural fields have diffffferent soil and land conditions. Uneven land, wet soil, stonesand irregular field boundaries can make machine operation diffffficult.Heavy machinery may also have diffffficulty working in wet or poorly drained fields. Machineryshould therefofore be selected according to local field conditions.

11. Soil Compaction

Continuous use of heavy agricultural machinery can increase soil compaction. Soil compactionreduces the spaces between soil particles and may affffect air and water movement in the soil.Excessive machinery traffffic can therefofore affffect soil health. Proper machine selection andcontrolled movement of machinery can help reduce this problem.

12. Environmental Problems

Excessive use of fuel-operated machinery can increase fuel consumption and emissions. It maycontribute to air pollution and greenhouse gas emissions.Improper use of machinery can also cause soil damage and increase environmental problems.Fuel-effffficient machines and appropriate mechanization can reduce these effffects.

13. Seasonal Use of Machinery

Many agricultural machines are required only during particular stages of crop production. Forexample, harvrvesters may be used mainly during harvrvesting periods.Therefofore, purchasing expensive machinery that remains unused fofor most of the year may notbe economical fofor small farmers. Machinery hiring servrvices can help farmers overcome thisproblem.

14. Custom Hiring Centres

Custom Hiring Centres provide agricultural machinery to farmers on a rental basis. Farmers canuse machines without purchasing them.This reduces the initial investment and makes modern machinery accessible to small andmarginal farmers. Custom hiring can also improve the effffficient use of available machinery.

15. Training and Skill Development

Proper training is necessary fofor farmers and machine operators. Training helps themunderstand machine operation, safety precautions, maintenance and proper adjustment.Demonstrations and skill-development programmes can increase the affffective use ofagricultural machinery and reduce machine-related accidents and breakdowns.

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16. Government Support

Government support can encourage farmers to adopt agricultural mechanization. Subsidies andaffffofordable loans can reduce the financial burden of purchasing machinery.Government programmes can also promote training, custom hiring centres and thedevelopment of suitable machinery for small farmers.

Conclusion

Agricultural mechanization plays an important role in modern crop production. It helps farmerscomplete agricultural operations on time, reduce labour requirements and improve effffficiency.However, high machinery cost, small land holdings, lack of skilled labour, technical knowledge,credit facilities, repair servrvices and suitable machinery are majajor challenges.These challenges can be reduced through affffofordable machines, custom hiring centres, propertraining, financial assistance, better repair facilities and suitable technologies. Proper andeffffficient mechanization can therefofore contribute to sustainable and productive modern crop production.

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Micronutrient Deficiency and Crop Productivity: Physiological Roles, Yield Impacts, And Management Strategies

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Introduction

Plant nutrition rests on a foundation of seventeen essential elements, of which eight — zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), boron (B), molybdenum (Mo), chlorine (Cl), and nickel (Ni) — are classified as micronutrients. Unlike the macronutrients nitrogen, phosphorus, and potassium, which plants require in quantities measured in tens to hundreds of kilograms per hectare, micronutrients are needed in amounts as small as fractions of a kilogram per hectare (Marschner, 2012). This distinction in quantity, however, has no bearing on biological importance. Macronutrients are largely structural and osmotic in function, forming the bulk of plant biomass and regulating water relations, whereas micronutrients act principally as enzyme cofactors, electron carriers, and structural components of specific metabolic complexes. A plant deprived of zinc or boron does not simply grow more slowly in a uniform sense; it experiences the selective failure of specific enzymatic pathways and developmental checkpoints, often with disproportionate consequences for reproductive success and yield relative to the minute quantity of nutrient withheld (Alloway, 2008).

The global distribution of micronutrient-deficient agricultural soils is extensive and geographically patterned. Calcareous soils, common across large parts of the Middle East, South Asia, and the Mediterranean basin, maintain high pH conditions that precipitate zinc, iron, and manganese into insoluble hydroxide and carbonate forms, rendering them largely unavailable to roots despite adequate total soil content. Highly leached, acidic soils typical of humid tropical regions exhibit the inverse problem for some elements: molybdenum availability collapses under low pH because molybdate ions bind strongly to iron and aluminum oxide surfaces, while boron and other mobile micronutrients are stripped from the profile by heavy rainfall. Sandy soils, low in both clay content and organic matter, lack the cation exchange capacity and chelating organic ligands needed to retain micronutrients against leaching losses, producing chronic deficiencies of zinc, boron, and manganese even where regional rainfall is moderate (Alloway, 2008; Cakmak, 2002). Sub-Saharan African arable soils illustrate the compounding effect of these factors, with zinc deficiency predominating alongside widespread co-occurring deficiencies of boron, iron, molybdenum, and copper across a range of soil types and management histories.

The agronomic consequence of this soil-level deficiency is compounded by a nutritional consequence often described as “hidden hunger.” Hidden hunger refers to a state of micronutrient malnutrition that produces no overt symptoms of caloric insufficiency yet still causes severe physiological harm, because the staple cereals and legumes that dominate diets in many developing regions are grown on micronutrient-poor soils and consequently carry low concentrations of zinc, iron, and other essential minerals in their edible tissues (Gregory et al., 2017). Zinc and iron deficiencies are estimated to affect roughly 30 percent and 60 percent of the global population, respectively, contributing to

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anemia, impaired immune function, stunted growth in children, and adverse pregnancy outcomes. Because the deficiency originates in the soil-plant continuum before it ever reaches the human diet, addressing hidden hunger increasingly requires agronomic intervention rather than downstream dietary supplementation alone. This reframes micronutrient management from a narrow yield-optimization concern into a matter of direct relevance to global food security and public health, and it is this dual productivity-and-nutrition imperative that motivates the detailed treatment of micronutrient physiology, soil dynamics, and correction strategies

Physiological Roles and Deficiency Symptoms in Crop Plants

Each essential micronutrient performs a distinct, non-substitutable biochemical function, and deficiency symptoms typically trace directly to the specific enzymatic or structural role that has been compromised. Zinc functions as a catalytic and structural cofactor in more than three hundred enzymes, including those governing auxin (indole-3-acetic acid) biosynthesis, and it plays a critical role in maintaining the structural integrity of cell membranes by stabilizing phospholipids and proteins against oxidative damage (Marschner, 2012). Zinc-deficient plants characteristically display interveinal chlorosis in younger leaves, shortened internodes producing a rosette growth habit, and small, malformed leaves — symptoms that follow directly from disrupted auxin transport and impaired cell elongation.

Iron and manganese share overlapping but distinct roles in the photosynthetic and respiratory electron transport chains. Iron is a core component of cytochromes, ferredoxin, and the iron-sulfur clusters of Photosystem I, making it indispensable for both chlorophyll biosynthesis and the electron transfer reactions of photosynthesis and mitochondrial respiration. Manganese is required for the water-splitting oxygen-evolving complex of Photosystem II and activates a range of enzymes involved in the Krebs cycle and lignin biosynthesis. Because both elements are essential to chlorophyll function, their deficiencies produce visually similar interveinal chlorosis, though iron deficiency typically manifests first and most severely in the youngest leaves due to its poor phloem mobility, while manganese deficiency chlorosis tends to appear with fine necrotic speckling across the interveinal tissue.

Boron and copper contribute primarily to structural and reproductive processes rather than to core metabolic catalysis. Boron cross-links pectin polysaccharides in the cell wall, stabilizing wall architecture and membrane function, and is essential for pollen tube growth and germination; reproductive tissues demonstrably require higher boron concentrations than vegetative tissues, making flowering and fruit set disproportionately sensitive to boron deficiency (Dell & Huang, 1997; Huang et al., 2009). Boron-deficient crops commonly show "flowering without seed setting," barren or malformed ears in maize, hollow stem disorders in brassicas, and reduced fruit set across horticultural species. Copper is required for lignification via its role in the enzyme polyphenol oxidase and in lignin-forming peroxidases, and copper-deficient cereals frequently exhibit pollen sterility and poor grain set, alongside twisted, chlorotic young leaves.

Molybdenum and nickel, though required in the smallest quantities of any essential element, govern nitrogen metabolism directly. Molybdenum is a structural cofactor of nitrate reductase, the enzyme that reduces nitrate to nitrite as the first step in nitrogen assimilation, and of nitrogenase in nitrogen-fixing symbioses; molybdenum-deficient plants accumulate nitrate and show nitrogen-starvation symptoms even in nitrogen-replete soils. Nickel is required to activate urease, the metalloenzyme that hydrolyzes urea into usable ammonium and carbon dioxide, and its omission causes urea accumulation and necrotic leaf-tip scorching, particularly in crops fertilized with urea-based nitrogen sources (Moraes et al., 2009). Both Mo and Ni deficiencies

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additionally suppress net photosynthetic rate and chlorophyll concentration, indicating an indirect but consistent link between nitrogen-metabolism micronutrients and overall photosynthetic capacity.

Across all eight elements, the underlying biochemical thread connecting deficiency to yield loss is the same: photosynthetic efficiency is degraded at the level of light capture, electron transport, or carbon assimilation, while reproductive development is disrupted at the level of pollen viability, fertilization, and grain or fruit set. Because yield formation depends on the successful conversion of photosynthate into harvestable reproductive structures, even marginal, visually asymptomatic micronutrient stress can produce substantial yield penalties before any diagnostic foliar symptom becomes apparent.

Soil Dynamics, Availability Factors, and Yield Penalties

Micronutrient availability in soil is governed less by total elemental content than by the chemical form in which that content exists, which is in turn controlled by pH, organic matter, redox potential, moisture, and texture. Soil pH is the single most influential variable: as pH rises above neutral, zinc, iron, manganese, and copper increasingly precipitate as insoluble hydroxides and carbonates, while molybdenum availability moves in the opposite direction, increasing with pH because molybdate desorbs from iron and aluminum oxide surfaces under alkaline conditions (Alloway, 2008). Organic matter buffers these effects by chelating micronutrient cations with organic ligands, keeping them in soluble, plant-available forms even where mineral solubility would otherwise be limiting; soils depleted of organic carbon through intensive cultivation therefore show accelerated micronutrient decline independent of their nominal total nutrient reserves. Redox potential governs the availability of iron and manganese in particular, since both elements shift between more soluble reduced forms and less soluble oxidized forms depending on waterlogging status, which explains why upland and paddy soils under the same parent material can exhibit markedly different iron and manganese behavior. Soil texture compounds all of these factors: sandy soils, with low clay and organic colloid content, retain little exchangeable micronutrient reserve and are disproportionately prone to leaching losses of boron and other mobile elements.

Nutrient interactions add a further layer of complexity beyond single-element soil chemistry. The most extensively documented antagonism is phosphorus-induced zinc deficiency, in which high rates of phosphate fertilization suppress zinc uptake and utilization through several compounding mechanisms: dilution of tissue zinc concentration by accelerated growth, reduced translocation of zinc from root to shoot, and the formation of insoluble zinc-phosphate complexes within plant tissue (Cakmak & Marschner, 1987). Field trials on wheat and cotton grown in phosphorus-deficient, zinc-deficient soils have repeatedly shown that heavy phosphorus application without corresponding zinc management depresses leaf area index, chlorophyll content, and ultimately grain and straw yield, even as it appears to correct the phosphorus deficiency itself. A parallel antagonism exists between iron and manganese, both of which compete for the same root uptake transporters and cellular binding sites; excess manganese in acidic, poorly drained soils can induce functional iron deficiency chlorosis even where total soil iron is adequate, and the reverse imbalance can suppress manganese-dependent photosystem function.

The cumulative yield consequences of micronutrient stress are substantial and well documented across major cropping systems. In cereals, zinc deficiency depresses tillering, leaf area development, and grain filling, with yield losses in severely deficient soils reaching levels sufficient to render cultivation marginal without correction. Boron deficiency in wheat, maize, and oilseed rape has been shown to reduce grain and seed yield primarily through

impaired pollen viability and fertilization failure rather than through vegetative growth suppression, meaning yield loss can occur even where the crop shows little outward vegetative symptomology. In legumes, molybdenum deficiency undermines both direct nitrate assimilation and symbiotic nitrogen fixation simultaneously, compounding nitrogen stress from two independent physiological pathways. Fruit and vegetable crops are particularly sensitive to boron and zinc shortfalls at flowering and fruit-set stages, producing not only reduced total yield but degraded harvest index and fruit quality — malformed, cracked, or hollow produce that carries reduced market value even where total biomass accumulation is only modestly affected.

Micronutrient status also interacts with abiotic stress tolerance in ways that amplify yield risk under climate variability. Zinc plays a documented role in detoxifying reactive oxygen species generated under drought and salinity stress, such that zinc-deficient crops show reduced capacity to manage oxidative damage under water limitation. Boron similarly contributes to membrane stability and water-use efficiency, with boron-adequate crops in several studies showing improved drought tolerance relative to boron-deficient counterparts. Because climate variability is increasing the frequency of drought and heat stress across many production regions, the interaction between micronutrient status and stress tolerance elevates the agronomic stakes of micronutrient management beyond simple yield maximization under optimal conditions, positioning it as a component of climate risk management as well as productivity management.

Diagnostic Techniques and Correction Strategies

Accurate diagnosis of micronutrient status precedes any effective correction strategy, and three complementary approaches are used in practice. Soil testing measures extractable micronutrient concentrations using standardized chemical extractants calibrated against crop response trials, providing a pre-planting estimate of deficiency risk and informing basal fertilizer planning; its principal limitation is that extractable soil concentration does not always translate directly into plant uptake, since uptake is mediated by root architecture, rhizosphere chemistry, and the interacting soil factors discussed above. Plant tissue analysis addresses this gap directly by measuring nutrient concentrations in specific plant organs, typically the most recently matured leaf, at defined growth stages, and comparing the result against established critical threshold values below which yield response to correction becomes likely. Tissue analysis is considered more diagnostically reliable than soil testing because it reflects the nutrient status the plant has actually achieved rather than a predicted availability, though it necessarily identifies deficiency only after the crop is already growing. Visual diagnosis, based on the characteristic symptom patterns described on Page 2, remains a valuable low-cost screening tool in the field, but its central weakness is that visible symptoms typically appear only after yield loss has already begun, since marginal or “hidden” deficiency well below the visual symptom threshold can still suppress yield substantially (Fageria et al., 2009). Effective micronutrient management therefore combines all three tools: soil testing for pre-season planning, tissue analysis for in-season confirmation and threshold-based decision-making, and visual monitoring as a rapid field-level early-warning system.

Correction of diagnosed deficiency is achieved through three principal application strategies, each suited to different deficiency severities, soil conditions, and crop growth stages. Soil application, whether as basal broadcast, banded, or incorporated fertilizer, remains the standard approach for correcting moderate to severe deficiencies with residual, multi-season benefit; chelated formulations, in which the micronutrient cation is bound to an organic ligand such as EDTA or DTPA, substantially improve uptake efficiency relative to non-chelated

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inorganic salts in high-pH or calcareous soils where free cations would otherwise rapidly precipitate, though chelated products carry a higher per-unit cost that must be weighed against their improved availability. Foliar sprays offer a faster-acting correction pathway, bypassing soil-level fixation entirely by delivering the nutrient directly to leaf tissue, and are particularly effective for immobile or moderately mobile elements such as zinc, iron, manganese, and boron where soil-level correction is slow or unreliable; timing is critical, since foliar applications are most effective when targeted to periods of peak physiological demand such as early reproductive development for boron and copper, and repeated low-dose applications generally outperform single high-concentration sprays in both efficacy and phytotoxicity risk (Fageria et al., 2009). Seed treatments, including seed priming with micronutrient solutions and seed coating with micro-formulations, provide a low-cost, low-dose correction method that supplies the germinating seedling with sufficient nutrient reserve to establish a healthy root system before soil-level correction becomes necessary, and are especially valuable for zinc and molybdenum in legume and cereal establishment.

Beyond correcting deficiency for the purpose of yield protection alone, targeted micronutrient management has become a central technique of agronomic biofortification, a strategy aimed at simultaneously raising crop yield and the nutritional density of the harvested product. Zinc and iron fertilization programs designed with grain nutrient loading as an explicit objective, rather than as an incidental by-product of deficiency correction, have demonstrated the capacity to substantially raise edible-tissue mineral concentration in staple cereals while maintaining or improving yield, offering a scalable complement to genetic biofortification breeding programs. Because agronomic biofortification operates through the same soil-testing, tissue-analysis, and application infrastructure already used for yield-focused correction, its marginal implementation cost for a farmer already practicing sound micronutrient management is comparatively low, making it one of the more immediately actionable interventions available for addressing hidden hunger at the production level rather than solely through post-harvest food fortification.

Integrated Nutrient Management, Innovations, and Conclusion

Micronutrient correction achieves its greatest and most durable benefit when embedded within a broader Integrated Nutrient Management (INM) program rather than applied as an isolated, one-off intervention. INM combines balanced nitrogen-phosphorus-potassium fertilization with organic amendments such as farmyard manure and compost, which supply the organic matter needed to chelate and retain applied micronutrients in plant-available form, alongside deliberate micronutrient inputs calibrated to soil-test and tissue-analysis results. This integration also manages the antagonistic interactions discussed on Page 3: balancing phosphorus rates against zinc status, for instance, prevents the induced-deficiency effect that heavy phosphorus fertilization alone would otherwise produce. Because micronutrient responses are highly site-specific, dependent on soil pH, organic matter, and texture, INM programs are most effective when calibrated to local soil survey data rather than applied as a uniform regional recommendation.

Several technological advancements are reshaping how micronutrient management is implemented at field scale. Nano-micronutrient fertilizers, formulated as nanoscale metal oxide particles such as zinc oxide and iron oxide, offer substantially greater surface area and reactivity than conventional salts, improving foliar uptake efficiency and, in trials on rice and other cereals, producing measurable increases in both yield and grain micronutrient content relative to conventional foliar sprays (Elshayb et al., 2021). Slow-release chelated formulations extend the effective duration of a single

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soil application by controlling the rate at which the micronutrient dissociates from its carrier matrix, reducing the fixation losses that limit the efficiency of conventional chelated products in high-pH soils. Smart soil mapping, using georeferenced soil-test and yield data, allows micronutrient deficiency risk to be modeled spatially across a field or region, directing limited fertilizer and diagnostic resources toward the areas of greatest agronomic need. These technologies converge most powerfully within precision agriculture systems, where variable-rate application equipment adjusts micronutrient dosing in real time according to soil sensor data and pre-built deficiency risk maps, in principle applying the same site-specific logic already established for macronutrient management to the more spatially heterogeneous problem of micronutrient correction.

CONCLUSION

Taken together, the evidence reviewed across this paper supports a clear synthesis: micronutrient management is not a peripheral refinement to be addressed only after macronutrient needs are satisfied, but a determining factor in whether nitrogen, phosphorus, and potassium inputs are converted into harvestable yield at all. Long-term yield optimization depends on sustaining soil micronutrient reserves through organic matter management and balanced fertilization rather than relying on episodic correction after visible deficiency symptoms appear, since much of the yield penalty associated with micronutrient stress occurs before symptoms become visually apparent. From an environmental sustainability standpoint, precise, diagnosis-driven micronutrient application reduces the risk of both under-application, which perpetuates yield loss and nutritional deficiency, and over-application, which can produce localized toxicity and unnecessary input cost. For farmers, the economic case is similarly favorable: because micronutrients are required in such small absolute quantities, the cost of correction is typically modest relative to the yield and quality gains achieved, giving micronutrient management one of the more favorable return-on-investment profiles among available agronomic interventions. As diagnostic tools, formulation technologies, and precision application systems continue to mature, micronutrient management is positioned to play an increasingly central role in closing both the yield gap and the nutritional gap that constrain global food systems today.

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Impact of Subsidies on Natural Farming Adoption

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Introduction

Natural farming is an approach to agriculture that aims to reduce dependence on synthetic fertilizers,Pesticides and other externally purchased chemical inputs. It emphasizes the use of locally availableBiological resources, farm residues, soil biological activity, biodiversity and ecological processes. The Transition from conventional farming to natural farming may require changes in farm management Knowledge, labour practices and marketing. Because farmers often face uncertainty during thisTransition, government subsidies and other forms of financial support can play an important role in Encouraging adoption.A subsidy is financial assistance provided by the government or another institution to reduce the cost or Risk associated with a particular activity. In natural farming, support may be directed towards training, Demonstrations, farm-level infrastructure, preparation of biological inputs, equipment, certification, Farmer groups and market development. The effectiveness of a subsidy depends not only on its amount. But also on how it is designed, delivered and combined with extension and market support.

Objectives of the Assignment

- To understand the role of subsidies in encouraging natural farming adoption.
- To examine the economic, social and environmental impacts of financial incentives.
- To identify the major benefits and limitations of subsidy-based programmes.
- To suggest measures for making subsidy support more effective and sustainable.

Why Subsidies Matter in Natural Farming

Farmers generally compare the expected benefits of a new farming practice with its costs, risks and Uncertainty. Natural farming may have low dependence on purchased chemical inputs, but farmers may still require training, labour, suitable equipment, biological inputs and time to adapt. Subsidies can lower these barriers and provide confidence to farmers who are considering a change.

Subsidies can be especially useful during the initial transition period. However, financial incentives alone are unlikely to guarantee long-term adoption. Farmers need reliable technical guidance, access to suitable local inputs, efficient extension services, producer organizations and profitable markets for Natural-farming produce.

Positive Economic Impact

- **Reduction in initial costs:** Financial assistance can help farmers meet expenses related to training, demonstrations, equipment and preparation of natural inputs.
- **Reduction in financial risk:** During the transition period, farmers may be uncertain about yield, labour requirements and market returns. Subsidies can reduce part of this perceived risk.

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- **Improved access for small farmers:** Small and marginal farmers may have fewer resources to experiment with new practices. Targeted support can make adoption more accessible.
- **Potential improvement in farm profitability**: When natural farming reduces dependence on purchased external inputs and yields are maintained, lower cultivation expenditure may improve net returns. The actual outcome varies by crop, location, management skill and market conditions.

Impact on Adoption Behaviour

Subsidies can influence farmers' decisions by making natural farming appear more feasible and less risky. A farmer who is interested but hesitant may be encouraged to attend training, establish a demonstration plot or try natural practices on part of the farm. When farmers observe successful results from their own fields or from neighbouring farms, confidence can increase and adoption may spread through farmer-to-farmer learning. Subsidies may also accelerate adoption when they are linked to extension activities.

For example, Financial assistance accompanied by practical demonstrations can help farmers understand how to prepare inputs, manage soil fertility, control pests using ecological methods and maintain farm records.

Social and Institutional Impact

- **Farmer participation:** Subsidy programmes can encourage farmers to join groups, demonstrations and training programmes.
- **Knowledge sharing**: Farmer groups and extension programmes create opportunities to exchange. practical experiences.
- **Women and youth participation**: Well-designed programmes can support skill development and enterprise opportunities in input preparation, processing, value addition and marketing.
- **Strengthening institutions**: Natural farming programmes can promote cooperation among farmers,extension agencies, local institutions and producer organizations.

Environmental Impact

The environmental benefits associated with natural farming may include reduced dependence on synthetic agricultural inputs, greater use of organic and biological resources, improved recycling of farm residues and increased attention to soil biological health. Greater crop diversity and ecological pest-management practices can also support farm biodiversity.

However, the environmental outcome depends on actual farm practices. A subsidy should therefore encourage correct adoption and not simply reward the purchase or distribution of inputs. Monitoring should focus on farming practices, resource use, soil management and long-term farm performance**.**

Limitations and Possible Negative Effects

- **Subsidy dependency**: Farmers may become dependent on incentives and may hesitate to continue when support ends.
- **Unequal access:** Complex application procedures, lack of awareness or documentation requirements can exclude some farmers.
- **Misallocation:** Weak monitoring can result in support being used for purposes unrelated to natural farming.
- **Short-term adoption:** Farmers may adopt practices only to receive benefits without developing long-term confidence or market connections.
- **Distortion of priorities:** Excessive emphasis on subsidies may reduce attention to

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productivity, profitability, soil health and consumer demand.

Challenges in Effective Implementation

The success of subsidy programmes depends on timely delivery, transparent eligibility criteria,local-level awareness and appropriate monitoring. Another important challenge is that natural farming practices can vary across crops, soils and regions. A uniform subsidy package may therefore not suit every farming system. Programmes should be flexible enough to reflect local conditions while maintaining clear standards.

Farmers also need assurance that natural-farming produce can reach consumers at remunerative prices. Without market demand, lower input costs alone may not provide sufficient motivation for continued adoption. Thus, subsidy policy should be connected with extension, value addition, aggregation and market development.

Measures to Improve Subsidy Effectiveness

- Provide subsidies together with practical, field-based training and continuous extension support.
- Give priority to small and marginal farmers and simplify application procedures.
- Use transparent digital and local monitoring systems to reduce leakage and improve accountability.
- Support farmer field schools, demonstrations and peer-to-peer learning.
- Link financial support with soil health improvement, biodiversity and resource recycling rather than only input distribution.
- Develop market linkages, aggregation, processing and value addition for natural-farming produce.
- Use outcome-based evaluation to measure adoption, farm economics and environmental performance.
- Gradually reduce dependence on direct subsidies by improving profitability, knowledge and market access.

Conclusion

Subsidies can act as an important catalyst for the adoption of natural farming by reducing initial costs, lowering perceived risk and encouraging farmers to access training and demonstrations. They can also contribute to environmental goals when they promote reduced dependence on synthetic inputs,recycling of farm resources and improved soil management.

At the same time, subsidies should not become the only reason for adoption. Long-term success depends on farmer knowledge, suitable practices, profitability, reliable markets and strong extension support. Therefore, the most effective policy approach is to use subsidies as a transitional and enabling mechanism while building a self-sustaining natural farming system. A well-designed programme should be farmer-friendly, transparent, locally adaptable and evaluated on real economic and environmental outcomes.

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Artificial Intelligence in Agronomic Decision Making

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Introduction

Agriculture is increasingly becoming a data-driven activity. Farmers and agronomists must make decisions about crop selection, sowing dates, irrigation, fertilization, pest management, weed control, harvesting, and marketing while dealing with uncertain weather, changing soil conditions, limited resources, and fluctuating market conditions. Artificial intelligence (AI) provides a collection of computational methods that can process large and complex datasets and convert them into useful predictions, classifications, recommendations, and alerts. In agronomy, AI can therefore support decision making by helping users understand field conditions and choose appropriate management actions.

Artificial intelligence in agronomic decision making refers to the use of machine learning, deep learning, computer vision, expert systems, natural-language systems, and related technologies to assist decisions concerning crop production and resource management. AI systems can combine information from soil tests, weather stations, satellites, drones, farm machinery, sensors, historical yield records, and management practices. The resulting analysis can provide field-specific information rather than relying only on generalized recommendations.

The importance of this approach is linked to the need for productive and sustainable agriculture. Water scarcity, soil degradation, climate variability, rising input costs, and pressure to reduce environmental impacts require decisions that are both timely and precise. AI does not replace agronomic knowledge; rather, it can extend the ability of farmers and professionals to analyze information and respond to variation within and between fields.

Objectives

• To explain the role of artificial intelligence in agronomic decision making.

• To describe major AI applications in crop and soil management.

• To examine the benefits and limitations of AI-based agricultural decisions.

• To discuss future opportunities for responsible adoption of AI in agriculture.

1. AI TECHNOLOGIES USED IN AGRONOMIC DECISION MAKING

1.1 Machine Learning

Machine learning (ML) enables a computer system to learn patterns from data and use those patterns to make predictions or classifications. In agriculture, ML can be used to estimate crop yield, identify disease risk, classify soils, predict irrigation requirements, and detect relationships between environmental variables and crop performance. Supervised learning methods use historical examples with known outcomes, while unsupervised methods can identify groups or patterns without predefined labels.

1.2 Deep Learning and Computer Vision

Deep learning is a branch of machine learning that is particularly useful for analyzing images and other

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complex data. Computer vision systems can examine photographs captured by smartphones, drones, or satellites to identify weeds, crop diseases, nutrient stress, plant damage, and differences in crop growth. Convolutional neural networks and related architectures have become important tools for image-based agricultural analysis.

1.3 Remote Sensing and Geographic Information

Remote sensing provides information about agricultural fields without requiring direct measurement at every location. Satellite and drone imagery can reveal vegetation patterns, moisture differences, crop development, and areas of stress. When AI algorithms analyze these images together with field observations, they can help produce management zones and identify locations that require further inspection.

1.4 Internet of Things and Sensor Data

Connected sensors can continuously measure variables such as soil moisture, temperature, electrical conductivity, humidity, and weather conditions. AI can combine these observations with historical information to detect patterns and generate alerts. For example, an irrigation-support system may estimate when crop water demand is likely to exceed available soil moisture and notify the farmer.

1.5 Expert Systems and Decision Support

Expert systems use rules, databases, and models to support decisions. Modern agricultural decision-support systems may combine rule-based agronomic knowledge with machine learning. Their purpose is to transform raw data into understandable recommendations, such as identifying a likely pest problem, suggesting when field scouting is needed, or highlighting a field zone that may require management attention.

1.6 Natural-Language Interfaces

Natural-language technologies allow users to interact with digital systems using ordinary language. In agriculture, this can make complex data more accessible to farmers who may not have specialized training in data analysis. A conversational interface can summarize field observations, explain trends, or help organize farm records, provided that its outputs are checked against reliable agronomic information.

2. APPLICATIONS OF AI IN AGRONOMIC DECISION MAKING

2.1 Crop Selection and Planning

AI can support crop planning by analyzing historical yields, soil characteristics, climate information, water availability, and management records. Such systems can identify relationships between environmental conditions and crop performance. The resulting information may help farmers compare possible crops or varieties for a particular location, although final decisions should also consider seed availability, local knowledge, economics, and risk.

2.2 Soil and Nutrient Management

Soil management is a major area for AI-assisted decision making. Algorithms can combine laboratory soil-test results, sensor measurements, terrain information, crop history, and remote sensing data to estimate spatial variability. This supports variable-rate nutrient management, where fertilizer applications are adjusted according to field conditions rather than treating an entire field as uniform. Better targeting can reduce unnecessary input use while maintaining crop productivity.

2.3 Irrigation Management

Water management can benefit from AI because crop water requirements change with weather, soil properties, growth stage, and irrigation history. AI systems can use weather forecasts, soil-moisture measurements, evapotranspiration estimates, and crop information to support irrigation scheduling. The objective is to provide enough water for healthy crop growth while avoiding unnecessary irrigation, waterlogging, and water loss.

2.4 Pest and Disease Detection

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AI-based image recognition can assist in identifying symptoms associated with pests and diseases. A farmer or field worker may capture an image of a plant, while an AI model compares visual characteristics with patterns learned from labeled examples. Early identification can support timely scouting and management. However, image-based predictions can be affected by lighting, image quality, crop variety, disease stage, and environmental conditions, so field confirmation remains important.

2.5 Weed Detection and Precision Management

Computer vision can distinguish crop plants from weeds in images. When integrated with precision machinery, this information can support targeted weed control rather than uniform treatment across a field. Such approaches may help reduce input use and improve the efficiency of field operations. Reliable performance depends on accurate training data and the ability of the system to handle different crop stages, weed species, and field conditions.

2.6 Yield Prediction and Harvest Planning

Yield prediction models can combine weather, crop-growth indicators, soil information, historical yields, and remote sensing data. More accurate estimates can support decisions about labor, storage, transport, machinery, and market planning. AI-based forecasts are estimates rather than guarantees and should be updated as new observations become available.

3. BENEFITS AND CHALLENGES

3.1 Major Benefits

• **Timely decisions:** AI can process incoming data quickly and identify changes that may require attention.

• **Precision management:** Field variability can be analyzed so that inputs and interventions are better matched to local conditions.

• **Resource efficiency:** Better estimates of water, nutrients, and crop needs can support more efficient use of agricultural resources.

• **Early detection:** Image and sensor analysis can identify potential crop stress, pests, or diseases before they become widespread.

• **Improved record use:** AI can turn historical farm records into information that supports planning and comparison across seasons.

• **Scalability:** Once appropriately developed and validated, digital systems can analyze large areas and large datasets more efficiently than manual analysis alone.

3.2 Challenges and Limitations

Despite its potential, AI should not be treated as an infallible source of agronomic advice. Model performance depends heavily on the quality, quantity, and representativeness of training data. A model trained under one climate, soil type, crop variety, or management system may perform poorly when transferred to another context. Local validation is therefore essential.

Data access is another challenge. Smallholder farmers may have limited access to reliable internet connectivity, sensors, high-quality imagery, or digital records. The cost of hardware, software, maintenance, and technical support can also limit adoption. Systems must therefore provide practical value relative to their cost and complexity.

Data privacy and ownership are important because farm data may contain commercially valuable information. Clear rules are needed concerning who owns data, who can access it, how it is stored, and how it may be used. Transparency is also important: farmers and agronomists should understand the main factors influencing an AI recommendation whenever possible.

Another limitation is the risk of over-reliance on automated recommendations. Agricultural decisions involve biological systems and uncertainty. AI predictions should be considered alongside field scouting, farmer experience, agronomic expertise, weather information, and other evidence. Human

oversight is particularly important when recommendations could have significant financial or environmental consequences.

3.3 Responsible Use

Responsible AI adoption should include field validation, regular model evaluation, clear communication of uncertainty, appropriate data protection, and opportunities for human review. Systems should be designed around real agricultural needs rather than technology alone. Training farmers and extension personnel is also important so that users can interpret AI outputs correctly.

4. FUTURE PROSPECTS AND CONCLUSION

4.1 Future Prospects

The future of AI in agronomy is likely to involve greater integration of multiple data sources. Instead of relying on a single image or sensor, decision-support systems can combine satellite observations, drone imagery, weather forecasts, soil measurements, machinery data, crop models, and farmer observations. This integrated approach can provide a more complete picture of field conditions.

Edge computing and improved connectivity may allow more agricultural data to be processed directly on farm equipment or mobile devices. This can reduce dependence on continuous internet access and support faster responses. Advances in explainable AI may also make recommendations easier to understand by showing which variables contributed most strongly to a prediction.

AI may increasingly support autonomous and semi-autonomous agricultural machinery. Field robots and intelligent equipment can use computer vision and sensors to identify plants, weeds, obstacles, and crop conditions. When combined with agronomic decision rules, these systems may enable more targeted field operations.

Another important direction is the development of farmer-centered AI. Systems should accommodate local languages, local cropping systems, small farms, and the practical knowledge of agricultural communities. Collaboration among farmers, agronomists, researchers, technology developers, extension services, and policymakers can improve the relevance and trustworthiness of these tools.

4.2 Conclusion

Artificial intelligence is becoming an important component of modern agronomic decision making. Machine learning, computer vision, remote sensing, sensor networks, expert systems, and natural-language technologies can help transform agricultural data into useful information for crop planning, soil and nutrient management, irrigation, pest and disease monitoring, weed control, and yield forecasting.

The greatest value of AI is not simply automation; it is the ability to support more informed, timely, and location-specific decisions. At the same time, AI has important limitations related to data quality, cost, transferability, privacy, interpretability, and the possibility of incorrect predictions. Consequently, AI should function as a decision-support tool rather than an unquestioned replacement for agronomic expertise.

A successful future for AI in agriculture will depend on responsible development, local validation, accessible technology, strong data governance, and meaningful involvement of farmers and agricultural professionals. When these conditions are met, AI can contribute to more efficient resource use, better monitoring of crop conditions, and more informed agronomic management.

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Farmers' Attitude Towards Natural Farming

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Introduction

Natural farming is a chemical-free, low-external-input farming approach based on locally available biological resources (cow dung, cow urine, farm biomass) that build soil microbial activity in place of synthetic fertilizers and pesticides. In India it is promoted under the Bhartiya Prakritik Krishi Paddhati (BPKP) and the National Mission on Natural Farming (NMNF). Since farmer adoption of any new practice is governed first by their psychological orientation towards it, the study of farmers' attitude is a key topic in Agricultural Extension Education.

Concept of attitude

Attitude is defined as a learned, relatively enduring predisposition to respond consistently in a favourable or unfavourable manner towards a given object, person, or practice. In extension education, attitude is treated as an internal psychological construct comprising three components:

- Cognitive component – the farmer's beliefs and knowledge about natural farming.
- Affective component– the farmer's feelings (like/dislike) towards the practice.
- Conative (behavioural) component – the farmer's tendency or intention to act (adopt/reject).

Measurement of attitude

Attitude towards natural farming is generally measured using a Likert-type summated rating scale, developed and standardised through statements covering economic, ecological, health and social dimensions of natural farming. Respondents rate each statement (Strongly Agree to Strongly Disagree), and scores are summed and categorised into Most Favourable, Favourable, Neutral, Unfavourable and Most Unfavourable attitude groups. Such scales form an important practical/statistical exercise in extension education courses.

Determinants of attitude

- Annual income - Positively correlated; higher income farmers show more favourable attitude
- Achievement motivation - Strong positive correlate; driven farmers are more receptive to new practices
- Economic motivation - Expectation of cost saving improves attitude
- Risk orientation - Farmers with higher risk-bearing capacity show more favourable attitude
- Social participation - Membership in farmer groups/exposure to demonstrations builds positive attitude
- Landholding size - Generally positive association with favourable attitude

Favorable perception

- Reduced input cost as farm-based inputs replace purchased chemicals.

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- Perceived improvement in soil fertility, moisture retention and long-term sustainability.

- Belief in producing safer, chemical-residue-free food for family and consumers.

- Sense of environmental stewardship and continuation of traditional farming knowledge.

Constraints affecting attitude

- Inadequate technical know-how of preparing Jeevamrutha, Beejamrutha and other inputs.

- Apprehension of yield decline in the initial transition period.

- Labour-intensive nature of input preparation and field operations.

- Non-availability of adequate cow dung/urine, especially for farmers with few cattle.

- Absence of assured premium markets or certification for natural produce.

- Limited awareness of government schemes supporting natural farming.

Research evidence

Studies conducted across agro-climatic zones (e.g., Tarai zone of Uttar Pradesh; Andhra Pradesh's ZBNF programme; apple orchards of Himachal Pradesh; South Gujarat) consistently report a predominantly favourable-to-neutral attitude among natural farming practitioners, with income and achievement motivation as the strongest positive predictors, while lack of technical knowledge and assured markets remain the leading constraints for non-adopters.

Educational implications

- Attitude assessment should precede the design of any extension programme promoting natural farming.

- Result demonstrations and farmer-to-farmer exposure visits help convert neutral/unfavourable attitudes into favourable ones.

- Sustained handholding, rather than one-time training, is necessary since attitude change is gradual.

- Strengthening market linkages and scheme awareness can reinforce the economic motivation component of attitude.

Conclusion

Farmers' attitude towards natural farming is shaped by an interaction of socio-economic factors (income, landholding), psychological factors (achievement and economic motivation, risk orientation) and situational factors (extension contact, market access). A generally positive but cautious attitude prevails among Indian farmers, and building it further requires an integrated extension strategy addressing both technical knowledge gaps and the underlying psychological determinants of attitude.

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Impact of Natural Farming on Soil Health

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Introduction

Natural farming is an ecological farming system that emphasizes the use of locally available natural resources and minimizes dependence on synthetic fertilizers, pesticides and other external inputs. It aims to maintain the natural processes of the soil–plant–microorganism system.

Soil health refers to the capacity of soil to function as a living ecosystem that supports plant growth, maintains environmental quality and sustains biological productivity. Healthy soil has good physical structure, adequate nutrients, active microorganisms and sufficient organic matter.

Natural farming can improve soil health by increasing organic matter, stimulating beneficial microorganisms, improving soil structure and reducing the harmful effects associated with excessive use of chemical inputs.

Objectives

The major objectives of studying the impact of natural farming on soil health are:

1. To understand the concept of soil health.

2. To study the principles of natural farming.

3. To examine the effect of natural farming on soil physical properties.

4. To understand its influence on soil chemical properties.

5. To study changes in soil biological activity.

6. To understand the role of natural inputs in maintaining soil fertility.

7. To promote sustainable and environmentally friendly agricultural practices.

Principles of Natural Farming

Natural farming is based on maintaining and improving natural ecological processes. Important principles include:

* Minimum disturbance of soil.

* Use of natural and locally available inputs.

* Recycling of crop residues and organic materials.

* Maintenance of soil moisture.

* Promotion of beneficial soil microorganisms.

* Use of botanical and biological methods for pest management.

* Avoidance or reduction of synthetic chemical inputs.

Impact of Natural Farming on Soil Health

A. Impact on Physical Properties of Soil

1. Improvement in Soil Structure

Natural farming encourages the addition and recycling of organic materials. Increased organic matter helps bind soil particles into stable aggregates.

Benefits:

* Better soil aggregation.

* Improved aeration.

* Reduced soil compaction.

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* Better root growth.

2. Increase in Water-Holding Capacity

Organic matter acts like a sponge and helps the soil retain water. This can improve the availability of moisture to crops, particularly during periods of limited rainfall.

3. Improved Infiltration

Improved soil aggregation creates pores through which water can enter the soil more easily. This reduces surface runoff and helps conserve rainfall.

4. Reduction in Soil Erosion

Natural farming practices such as mulching, cover crops and maintaining plant residues protect the soil surface from the direct impact of rainfall and wind.

B. Impact on Chemical Properties of Soil

1. Increase in Soil Organic Matter

Regular recycling of crop residues and the use of organic materials can increase soil organic carbon over time. Soil organic matter is important for maintaining fertility and soil structure.

2. Better Nutrient Cycling

Natural farming promotes microbial activity and decomposition of organic materials. Nutrients are gradually released and recycled within the soil system.

Important nutrients include:

* Nitrogen (N)

* Phosphorus (P)

* Potassium (K)

* Sulphur (S)

* Micronutrients such as zinc and iron

3. Improved Cation Exchange Capacity

Organic matter contributes to the soil's cation exchange capacity (CEC), which helps the soil retain positively charged nutrients such as calcium, magnesium and potassium.

4. Reduced Chemical Residues

Reducing the use of synthetic fertilizers and pesticides can decrease the risk of accumulation of certain agricultural chemical residues and their adverse effects on soil organisms.

Impact on Biological Properties of Soil

Soil is a living ecosystem containing bacteria, fungi, actinomycetes, earthworms and other organisms. Natural farming can support this biological community.

1. Increased Microbial Activity

Organic materials provide energy and nutrients for soil microorganisms. Beneficial microorganisms participate in decomposition and nutrient cycling.

2. Greater Microbial Diversity

Reduced chemical disturbance and increased availability of organic substrates can create conditions favourable for diverse soil microbial communities.

3. Earthworm Activity

Organic matter and reduced soil disturbance can favour earthworm populations. Earthworms improve soil aggregation and help mix organic materials into the soil.

4. Improved Nutrient Mineralization

Microorganisms convert nutrients present in organic materials into forms that can become available to plants.

Advantages of Natural Farming for Soil Health

1. Improves soil organic matter.

2. Promotes beneficial soil microorganisms.

3. Improves soil structure.

4. Enhances water-holding capacity.

5. Reduces soil erosion.

6. Supports nutrient cycling.

7. Encourages earthworm and soil fauna activity.

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8. Reduces dependence on synthetic agricultural inputs.

9. Supports long-term soil fertility.

10. Promotes sustainable agricultural production.

Limitations and Considerations

Natural farming is not automatically beneficial under every situation. Its success depends on proper management and local conditions.

Some challenges include:

* Nutrient availability may be slow.

* Large amounts of biomass may be required for mulching.

* Yield responses can vary between crops and soils.

* Natural inputs need proper preparation and application.

* Weed management can be challenging.

* Farmers may require training and technical knowledge.

* Long-term field studies are important for evaluating changes in soil health.

Therefore, natural farming practices should be selected according to soil type, crop, climate and availability of resources.

Conclusion

Natural farming is an approach that seeks to work with natural ecological processes rather than relying heavily on external synthetic inputs. Through practices such as mulching, crop-residue recycling, crop diversification, minimum soil disturbance and the use of organic and biological inputs, natural farming can contribute to improved soil physical, chemical and biological properties.

The most important long-term benefits include improved soil organic matter, better soil structure, enhanced microbial activity, improved water conservation and efficient nutrient cycling. However, results can vary depending on soil type, climate, crop and management practices. Therefore, scientific evaluation and locally suitable management are essential for achieving sustainable soil health through natural farming.

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Evolution of Agricultural Extension in Natural Farming

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Introduction

Agricultural extension work has a venerable, albeit largely unrecorded, history. It is a significant social innovation, an important force in agricultural change, which has been created and recreated, adapted and developed over the centuries. Its evolution extends over nearly four thousand years, although its modem forms are largely a product of the past two centuries. Today, the organizations and personnel engaged in agricultural extension encompass a diverse range of socially sanctioned and legitimate activities which seek to enlarge and improve the abilities of farm people to adopt more appropriate and often new practices and to adjust to changing conditions and societal needs.

The overt use of the notion of "extending" relevant and useful information to the adult population at large, however, predates the university extension movement. Earlier in the nineteenth century, a British politician, Lord Henry Brougham, an influential advocate of formal education for the poor and of mass adult education, founded the Society for the Diffusion of Useful Knowledge in 1826. Its objective was "imparting useful information to all classes of the community, particularly to such as are unable to avail themselves of experienced teachers, or may prefer learning by themselves." The society sought to do this largely through producing low-priced publications and establishing local committees throughout the country "for extending the object of the Society" (Society for the Diffusion of Useful Knowledge 1827). During its twenty years' existence, agricultural topics were well covered in the society's publications. Similar, albeit short-lived, societies were also established before 1840 in several other European countries, India, China, Malaysia, and the United States (in Virginia) (Grobel, 1933; Smith, 1979.

The distant origins:

The dissemination of relevant information and advice to farmers, however, has a long if chequered history prior to the emergence of modem forms of agricultural extension in the nineteenth century.

The first known example was in Mesopotamia (roughly, present-day Iraq) around 1800 B.C.

Archaeologists have unearthed clay tablets of the time on which were inscribed advice on watering crops and getting rid of rats - important for mitigating any potential loss of taxation revenue from farmers (Ahmed, 1982, as quoted in Bane Saad, 1990). Some hieroglyphs on Egyptian columns also gave advice on avoiding crop damage and loss of life from the Nile's floods. An important advance was the beginning of agricultural writings. Though few have survived, the earliest were written during the ancient Greek and Phoenician civilizations, but some of them were adapted by Roman writers. From the second century B.C. to the fourth century A.D., several important Latin texts were written, frequently drawing on practical farming experience, which aimed to help Roman landowners to maintain and improve then-estates and their revenues (White, 1970, 1977).

At around the same period in imperial China, early forms of advancing and disseminating agricultural

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information also began. That landowners and their tenants should improve their production was a matter of concern to the state since, from the sixth century B.C. onwards, it relied heavily on land taxes for its revenues. The support of relevant agricultural research and the dissemination of information and advice had certainly begun by the late Han Dynasty (25-220 A.D.). The oldest fully surviving Chinese agricultural treatise, Essential Techniques/or the Peasantry, dating from 535 A.D., aimed to show landowners how to improve their estate management through the advice they gave to their tenants. The Sung and Yuan Dynasties (960-1368) with their firm local government administrations were notable in organizing and promoting agricultural research, extension work, and the teaching of agriculture and sericulture, much facilitated by the invention of woodblock printing, which allowed agricultural treatises and practical handbooks to be widely distributed. Similar activities continued during the succeeding Ming (1368-1644) and Chi'ing (1644-1912) Dynasties, driven not only by the growing population and periodic threats of famine, but also by the state's recognition of the importance of well-coordinated extension work on agricultural recommendations if the most benefit was to be achieved (Perkins, 1969; Elvin, 1973; Bray, 1984; Delman, 1991).

Necessary conditions for agricultural extension to evolve:

Apart from the importance of farmers and agriculture in the society and economy concerned, several conditions appear to be necessary for the initiation and organized development of agricultural extension work.

The prime condition is that information has been assembled, systematized, and made available on good or progressive or new agricultural practices suited to a particular environment, and is based on either (or both) the accumulation of experience or findings from research (however rudimentary). Second, this information is used, among other things, to educate professional agriculturists who may further enlarge or refine this body of knowledge or become active promoters and disseminators of it. Third, an appropriate administrative or organizational structure exists by and within which the dissemination activities may be established and conducted. Fourth, there is a legislative or some other official mandate or influential proponent which prescribes or enables that agricultural extension work is desirable and must occur. Fifth, there are invariably a variety of antecedents which have attempted protoforms of agricultural information and advice dissemination. In addition, the incidence of critical situations, such as famine, crop failure, soil exhaustion, or altered economic conditions or relationships, may create an immediate cause for initiating the organization of extension work. All or several of these conditions have been present in the evolution of modem forms of agricultural extension.

Towards the Modern Era:

The direct antecedents of organized agricultural research and dissemination of its results which occurred in nineteenth century Europe and North America can be traced back to the "renaissance" which began in the fourteenth century. Between 1300 and 1700, European society became transformed from its medieval feudal forms into recognizably modem social systems. It was a period of complex, multistranded development. Along with the growth of national states and European exploration and "discovery" of the rest of the world was the "new learning." This involved not only a fresh appreciation of rediscovered classical writings and art forms, but also many novel ideas and activities, a spirit of humanism, and rational enquiry. All of this was considerably facilitated by the invention of printing using movable type, usually attributed to Gutenberg around 1450, and the rapid diffusion over Europe of the printing press, for whose output there existed a ready market.

The earliest known renaissance agricultural text was written in Latin by Pietro de Crescenzi in 1304 and

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was translated into Italian and French. This became the first book on agriculture to be printed in the mid-fifteenth century. Others soon followed, often based on the old Latin texts or on the collected wisdom of farmers and their families. A well-known example, a compendium of helpful advice in simple verse and a bestseller in Tudor England, was Thomas Tusser's A hundredth good pointes of husbandary published in 1557 and expanded in 1573 to five hundred good points with as many on "goode housewiferie" (Tusser, 1580). Less popular, but of greater significance, were Francis Bacon's writings early in the next century based on his observations and scientific experiments on his estate north of London - the beginnings of the application of science and scientific method to agriculture (Russell, 1966).

By the mid-eighteenth century, throughout much of Europe, progressive landowners (frequently aristocrats) and their agents and a few similarly minded farmers were being known as "improvers." These, along with some "men of science," were the main proponents of agricultural clubs or societies. At their regular meetings and demonstrations, locally and regionally, landowners and leading farmers exchanged ideas and information and discussed farming improvements. Two main forces underlay the movement. First, many landowners were eager to learn of ways to improve their estates and the production capabilities of their tenants so as to increase the value of their estates and their rental incomes. Secondly, progress was being made towards modern science and its application to agriculture, especially in agricultural chemistry and plant physiology (Russell, 1966). These societies sought to alter radically the traditional modes of farming by initiating experiments, arranging demonstrations, disseminating information, and advocating the adoption of innovations. It was considered almost a duty by their elite membership to make their initiatives and activities known to "the generality" of farmers through publishing their proceedings and reporting their meetings in newspapers (Hudson, 1972). Although such agricultural societies initially spread slowly - the first had been formed at Rezzato near Milan in 1548 (Coletti, 1900) - they had become common throughout much of Europe by 1800, and a small number had been established by that year in the young United States and eastern Canada. It is not possible, here, to enter into detail on the interactions between a growing scientific knowledge of agriculture and its application in practice, the many examples of increasingly widespread agricultural improvement, and the numerous personalities involved in Europe and North America during the century or so after 1750. Reference must, however, be made to one figure whose ideas and activities were of pivotal significance to the developments of the time, and later. This was Philipp Emanuel von Fellenberg (1771-1844), who in 1799 purchased the estate of Wylhof, which he renamed Hofwyl, near Bern in Switzerland (Gray, 1952; Guggisberg, 1953). Over the next decade or so, he established agricultural schools at Hofwyl for the children of peasants and of the poor and for the aristocracy and their agents. Although not the first agricultural schools in Europe, those of von Fellenberg became a model for many more which were established before 1850, especially in Denmark, Germany, France, and the United Kingdom, thus assuring a cadre of trained agriculturists.

At Hofwyl, von Fellenberg also established an experimental-cum-model farm to test and develop suitable husbandry practices and technology. He publicised the work at this veritable "educational colony" through a journal and agricultural festivals (shows) at Hofwyl and by welcoming a large number of visitors from all over Europe and maintaining a voluminous correspondence with these and others. Many of his visitors became active proselytes of his methods, recognizing their practical value in disseminating useful information on agriculture - and other topics. One such notable visitor was Lord Henry Brougham, referred to earlier, who became the

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main publicist of von Fellenberg's work in Britain and whose Society for the Diffusion of Useful Knowledge was an early form of organized "extension."

By the 1820s, most of the elements for creating modem forms of agricultural extension were in being, although each was to develop considerably during the nineteenth century. A crucial missing element, however, was an effective means by which the "generality" of farmers could be directly given information, advice, and encouragement. This required itinerant agriculturists who could meet farmers in their home localities, give instructional talks and demonstrations, advocate superior or new practices, and have discussions with the farmers. The notion of "itinerancy" was not new: since late medieval times, tradesmen and proto-professional men had travelled through rural areas to serve their clients. The first examples of itinerant agricultural lecturers-cum-instructors were in parts of New England and New York in the 1820s (True, 1928) and in France, where a first migratory agricultural teacher was appointed in the Gironde in 1837, followed by nine more in various areas of the country in succeeding years (Boulet n.d.). During the 1840s, further sporadic developments also occurred in the United States, particularly in New York, Ohio, and Maryland (True, 1928), while in Württemberg, in southwest Germany, a pasture specialist (Wiesenbaumeister) together with a staff of eighteen technicians was employed by the state agricultural society to advise farmers, landowners, and town administrations on land drainage, irrigation, and improved pasture management (CLVS, 1845).

Conclusion:

In Europe, agricultural science was evolving rapidly by the 1840s, with notable strides being made in

Germany by Justus von Liebig at Giessen, and with the establishment of agricultural experiments at Rothamsted in England in 1843 by John Bennet Lawes and Henry Gilbert. Agricultural societies and their shows were flourishing. Numerous publications and periodicals were aimed at farmers. Agricultural schools, if not commonplace, had been established in most European countries. Thus a small minority of younger landowners and farmers had received a formal education in their calling, while purposely trained agriculturists were available to be engaged as estate agents or teachers. Many of the more progressive landowners employed agents to travel around their estates to urge improved methods on their tenants. The main element necessary to create modern agricultural extension services was for legitimate authorities to establish the necessary organizations - and the germ of this had already been present in France, Germany, and the United States.

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Effect of Natural Farming on Sugarcane Productivity

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Introduction

Sugarcane (*Saccharum officinarum*) is one of the most important commercial crops grown in India. It provides raw material for sugar, ethanol, molasses, and other industries. Sugarcane requires considerable amounts of water and nutrients and is generally cultivated for a long duration.

Natural farming is an ecological farming system that reduces dependence on synthetic fertilizers, pesticides, and other external inputs. It promotes the use of locally available resources such as farmyard manure, crop residues, cow-based formulations, mulching, and natural pest-management practices,

Natural farming can improve soil health, increase biological activity, conserve moisture, and reduce cultivation costs. These changes can influence the growth and productivity of sugarcane.

2. Objectives

The major objectives of studying the effect of natural farming on sugarcane productivity are:

- To study the influence of natural farming practices on sugarcane growth.
- To understand the effect of natural inputs on cane yield and quality.
- To improve soil fertility and soil biological activity.
- To reduce the dependence on chemical fertilizers and pesticides.
- To reduce the cost of sugarcane cultivation.
- To promote sustainable and environmentally friendly sugarcane production.

3. Natural Farming Practices in Sugarcane

A. Use of Natural Inputs

Natural farming makes use of locally available biological and organic inputs such as:

o Jeevamrit – promotes microbial activity in the soil. o Beejamrit – used for seed/sett treatment. o Panchagavya – used as a growth-promoting preparation. o Farmyard manure (FYM) – improves soil structure and nutrient availability. o Compost – adds organic matter to the soil. o Botanical extracts – help in managing insect pests naturally.

B. Mulching

Sugarcane produces a large quantity of dry leaves. These leaves can be used as trash mulch between the rows.

Mulching:

- Conserves soil moisture.
- Reduces weed growth.
- Moderates soil temperature.
- Adds organic matter after decomposition. ▪ Encourages beneficial soil organisms.

C. Intercropping

Short-duration crops such as pulses can be grown between sugarcane rows where suitable.

Benefits include:

- Better utilization of land.
- Additional income to farmers.

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- Improvement in sioil fertility, particularly through legumes. ▪ Reduction in weed growth.

D. **Natural Pest and Disease Management**

Natural farming emphasizes preventive and biological methods such as:

- Neem-based preparations.
- Botanical extracts.
- Biological control agents.
- Maintaining field sanitation.
- Encouraging beneficial insects.
- Crop diversification.

4 Effect on Sugarcane Growth and. Productivity

4.1 Effect on Germination and Establishment

Proper treatment of sugarcane setts with biological preparations and maintaining suitable soil moisture can promote healthy establishment. Good initial establishment results in better plant population and uniform crop growth.

4.2 Effect on Root Development

Natural farming practices increase organic matter and biological activity in the rhizosphere. Improved soil conditions can encourage better root growth, allowing the crop to utilize available water and nutrients more efficiently.

4.3 Effect on Tillering

Healthy soil conditions and adequate nutrient availability can support better tillering. A higher number of healthy tillers can contribute to an increased number of harvestable canes.

4.4 Effect on Cane Growth

Natural inputs supply nutrients gradually and improve soil physical conditions. Mulching also helps maintain soil moisture, which is important for the long-duration growth of sugarcane.

4.5 Effect on Cane Yield

The yield of sugarcane depends on factors such as:

Number of millable canes × individual cane weight

Natural farming may improve these yield components by maintaining better soil moisture, nutrient cycling, and crop health.

However, yield response is not uniform in every location. It depends on soil type, climate, variety, irrigation, nutrient availability, and the quality and management of natural inputs.

5. Effect on Sugarcane Quality

Natural farming may also influence the quality of harvested cane.

Important quality parameters include:

- Brix – percentage of soluble solids.
- Pol % – approximate sucrose content.
- Purity – quality of juice based on sugar and soluble solids.
- Sugar recovery – amount of sugar obtained from the processed cane.
- Balanced crop nutrition and proper water management are important for maintaining good cane quality.

6. Effect on Soil Health

One of the major advantages of natural farming is its potential to improve soil health.

Regular use of organic materials and crop residues can:

- Increase soil organic carbon.
- Improve soil structure.
- Increase microbial activity.
- Improve water-holding capacity.
- Improve nutrient cycling.
- Reduce soil degradation.

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This is particularly important for sugarcane because it remains in the field for a relatively long period.

7. Effect on Water Requirement

Sugarcane is a water-demanding crop. Natural farming practices such as mulching and improvement of soil organic matter can help conserve soil moisture.

Therefore, natural farming can contribute to:

Better moisture conservation → improved water-use efficiency → reduced moisture stress

However, natural farming does not automatically eliminate the need for irrigation. Proper irrigation management remains essential, especially in water-limited areas.

8. Effect on Cost of Cultivation

Natural farming can reduce expenditure on external agricultural inputs by encouraging the use of farm-available resources.

Possible savings include:

- Reduced expenditure on synthetic fertilizers.
- Reduced pesticide costs.
- Reduced dependence on purchased inputs.
- Better utilization of crop residues.

This may improve the net returns of farmers if acceptable yields are maintained.

9. Environmental Benefits

Natural farming can contribute to environmental sustainability through:

- Reduced chemical input use
- Improved soil biodiversity
- Better recycling of farm residues
- Reduced risk of chemical contamination
- Improved soil and water conservation
- Support for beneficial organisms

Thus, it can help move sugarcane cultivation towards a more sustainable production system.

10. Limitations and Challenges

Although natural farming has several potential benefits, some challenges should also be considered:

- Yield reduction may occur if nutrients are not adequately supplied.
- Preparation of natural inputs requires labour and regular management.
- Nutrient availability from organic sources can be slower than from soluble fertilizers.
- Results may vary depending on soil and climatic conditions.
- Large-scale sugarcane production requires careful nutrient and water management.
- Farmers may require proper training and technical guidance.
- More long-term, location-specific research is required to determine the most effective natural farming practices for sugarcane.

11. Overall Impact

The effect of natural farming on sugarcane can be represented as:

Natural Farming Practices

↓

Organic & Biological Inputs + Mulching + Natural Pest Management

↓

Improved Soil Biological Activity & Moisture Conservation

↓

Better Root Growth & Nutrient Cycling

↓

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Healthy Crop Growth

↓

Improved Yield Components & Cane Quality

↓

Lower External Input Cost + Better Soil Health

↓

Sustainable Sugarcane Production

12. Conclusion

Natural farming offers a promising approach for making sugarcane cultivation more sustainable, resource-efficient, and environmentally friendly. Practices such as mulching, recycling of crop residues, use of biological inputs, and natural pest management can improve soil health and moisture conservation and may support better crop growth.

However, the effect on sugarcane productivity depends strongly on site-specific conditions and proper nutrient and water management. Therefore, natural farming should be adopted based on scientific evaluation and local suitability rather than assuming that eliminating all external inputs will always increase yield.

In conclusion, natural farming has the potential to maintain or improve sugarcane productivity while reducing input costs and improving long-term soil health, when properly planned and managed.

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Site Specific Weed Management In Field Crops

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1.Introduction

Weeds are unwanted plants that grow along with crops without being deliberately sown. They grow fast, produce many seeds, and often host pests and diseases, causing serious problems in cultivated fields. Weeds compete directly with crops for water, nutrients, sunlight and space, and since they usually grow faster than crop seedlings, they take a larger share of these resources. This competition weakens crop growth, reduces plant height, and can cause yield losses ranging from 20% to 80% depending on crop and weed pressure. Proper weed management is therefore essential to protect crop growth and yield, and control practices must be chosen according to actual field conditions rather than applied uniformly, which is the basis of site specific weed management.

2. DEFINITION

Site Specific Weed Management (SSWM) means controlling weeds according to the actual weed situation found at each location in a field, instead of applying the same treatment uniformly everywhere. Weed management, in general, refers to all activities used to prevent, identify and control unwanted plants (weeds) so that they do not harm the crop. It is important because weeds compete with crops for water, nutrients, light and space, reducing yield if not controlled. Weed type, density and spread often differ from field to field, and even within the same field, due to differences in soil, moisture and drainage. The basic idea of SSWM is to study these differences and select the most suitable control method for each particular site.

3. IMPORTANCE OF WEED MANAGEMENT

- Reduces crop-weed competition for resources.
- Improves overall crop growth and root development.
- Increases crop yield and produce quality.
- Ensures efficient use of applied water and nutrients.
- Reduces overall production cost.
- Makes harvesting, manual or mechanical, easier.
- Prevents build-up of pests and diseases hosted by weeds.
- Protects soil health and the environment.

4. OBJECTIVES OF SITE SPECIFIC WEED MANAGEMENT

1. Correct identification of weed species present.
2. Locating weed-infested areas within the field.
3. Selecting the most suitable control method for each site.
4. Ensuring timely weed control at the correct crop stage.
5. Reducing unnecessary and excess herbicide use.
6. Reducing labour and overall production cost.
7. Protecting crop yield from weed competition.
8. Making efficient use of agricultural inputs.
9. Protecting the environment from chemical overuse.

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10. Promoting sustainable, long-term agriculture.

5. FACTORS AFFECTING WEED MANAGEMENT

The choice of weed management method depends on several factors that must be studied before deciding the type, dose and timing of control.

- Type of weed – grasses, sedges or broad-leaved weeds respond differently to control methods.
- Weed density – higher density needs stronger or repeated control.
- Crop type – control method must suit the crop's tolerance.
- Crop growth stage – determines the critical period for weed control.
- Soil type – affects weed germination and herbicide movement.
- Soil moisture – influences weed growth and herbicide performance.
- Climate and rainfall – affect growth rate and herbicide effectiveness.
- Irrigation method – influences which weed species dominate.
- Cropping system – continuous cropping favours specific weeds.
- Field condition – drainage and weed history affect infestation level.

6. METHODS OF WEED MANAGEMENT

6.1 Preventive Method

Prevents entry and spread of weeds using clean seed, clean machinery, clean manure and clean field bunds. It is the cheapest and first line of weed defence.

6.2 Cultural Method

Uses normal crop practices to suppress weeds: crop rotation, proper spacing, timely sowing, thorough land preparation, optimum plant population and proper irrigation, all of which help the crop compete better against weeds.

6.3 Mechanical Method

Includes tillage, inter-cultivation, hand hoeing, mechanical weeders and mowing, all of which physically remove or destroy weeds using tools or machines.

6.4 Manual Method

Hand weeding removes weeds by hand or simple tools. It allows selective removal without crop damage and is important where herbicides cannot be used.

6.5 Chemical Method

Herbicides are chemicals that kill or suppress weeds. They save labour and control weeds quickly, but must be applied at the recommended dose, correct time and proper method to avoid crop damage and herbicide resistance.

6.6 Biological Method

Uses living organisms such as insects, fungi or grazing animals to suppress specific weeds. It is slow but environmentally safe and useful for long-term control.

6.7 Integrated Weed Management

Combines two or more methods (cultural, mechanical, manual, chemical, biological) for more effective, economical and sustainable weed control, reducing dependence on any single method and lowering herbicide resistance risk.

7. SITE-BASED WEED IDENTIFICATION

Before selecting a control method, weeds must be identified according to their location in the field, through:

- Field observation and weed species identification.
- Weed density and distribution across the field.
- Weed growth stage and crop growth stage.

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- Marking high weed infestation zones.
- Soil and moisture variation across sites.

Correct identification is essential because wrong identification leads to wrong method selection, poor control, wasted resources and possible crop damage.

8. MODERN TECHNOLOGIES IN WEED MANAGEMENT

- GPS – records exact locations of weed-infested spots for accurate revisits and treatment.
- GIS – prepares weed distribution maps by combining weed data with location.
- Remote Sensing – uses satellite/aerial images to detect weed patches over large areas.
- Drones – capture field images to quickly identify weed patches from above.
- Sensors – detect differences between crop and weed reflectance in real time.
- Artificial Intelligence – analyses images to identify weed species and density accurately, improving spray decisions.

9. SITE SPECIFIC WEED MANAGEMENT IN FIELD CROPS

Rice

Grassy weeds, sedges and broad-leaved weeds are common. Proper levelling, timely transplanting, standing water management and need-based herbicide/hand weeding control weeds effectively.

Maize

Weeds compete heavily in the first 30–45 days. Timely inter-cultivation, hand weeding and pre-emergence herbicide in infested patches are effective.

Cotton

Wide spacing and slow early growth make cotton vulnerable to weeds. Land preparation, inter-cultivation and targeted herbicide use in dense patches help control.

Groundnut

Weed control is critical before pegging; one or two hand weedings and timely inter-cultivation protect pod development.

Wheat

Broad-leaved and grassy weeds are common, especially under irrigation. Land levelling and post-emergence herbicide in infested zones give good control.

Pulses

Slow initial growth makes pulses poor competitors. Timely sowing, optimum population and selective weeding in the first 4–6 weeks protect yield.

10. ADVANTAGES

11. Effective, accurate weed control at each site.
12. Reduced herbicide use.
13. Reduced labour requirement.
14. Lower overall production cost.
15. Saves time in field operations.
16. Efficient use of farm inputs.
17. Better crop growth and canopy development.
18. Protection of yield potential.
19. Reduced environmental pollution.
20. Supports sustainable agriculture.

11. LIMITATIONS

- High initial cost of advanced technologies.
- Requires technical knowledge and training.
- Needs regular, time-consuming field monitoring.
- Some weeds are difficult to identify accurately.
- Limited availability of drones and sensors in rural areas.
- Weather affects image and sensor accuracy.
- Requires proper data collection and analysis.

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- Difficult for small farmers to afford expensive technology.

12. ROLE OF FARMERS

- Regular field observation and early weed identification.
- Monitoring weed density across the field.
- Selecting suitable control methods for each site.
- Carrying out timely weed control.
- Using herbicides properly and at recommended dose.
- Keeping field boundaries clean.
- Monitoring the field after treatment.
- Adopting modern technology where feasible.

13. FUTURE SCOPE

The future of weed management lies in precision agriculture tools such as drones, sensors, Artificial Intelligence, robotics, GPS, GIS, remote sensing and smart spraying systems, which will allow faster, more accurate weed detection and targeted herbicide application, making weed management more precise, economical and eco-friendly.

14. CONCLUSION

Site Specific Weed Management is an effective approach that recognises how weed problems differ from field to field and even within the same field. By correctly identifying weed type, density and distribution, and by studying soil, moisture and crop growth stage, farmers can select the most suitable method, whether cultural, mechanical, manual, chemical or biological, for each site. Combined with modern technologies like GPS, GIS, remote sensing, drones, sensors and Artificial Intelligence, this approach reduces unnecessary input use, lowers production cost, improves crop growth and yield, and protects soil and environmental health, thereby promoting sustainable and economically viable agriculture.

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Heat Stress During Reproductive Stage in Mustard Crop

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Introduction

Mustard [Brassica juncea] is the second most important oilseed crop in India after soybean. India contributes 28% of world mustard production. Rajasthan, Haryana, MP, UP and Gujarat are major states. It is a winter season crop, needs cool and dry climate.[Rabi]

Thermal requirement of mustard

- Germination: 20-25°C

- Vegetative growth: 15-20°C

- Reproductive stage [flowering to maturity]: 20-25°C optimum

- Above 28°C - stress starts

- Above 32°C - severe damage to pollen and pod formation

Crop phenology: Sowing in Oct-Nov, Flower initiation 45-55 DAS, Full flowering 60-80 DAS, Pod filling 80-110 DAS, Maturity 120-140 DAS.

Reproductive stage is most critical because 75% of yield comes from successful flowering and pod filling. Any high temperature at this stage is called *Terminal Heat Stress*. In North India, Feb-March temperature now crosses 32-35°C due to climate change, coinciding exactly with mustard flowering. This is why average mustard yield in India is only 15 q/ha while potential is 25 q/ha.

Reason for increasing heat stress:

1. Late sowing due to late harvest of Kharif rice

2. Global warming - 1.2°C rise in winter temperature in last 20 years

3. Shorter winter, early summer onset

4. Lack of irrigation at critical stage

EFFECT OF HEAT STRESS ON REPRODUCTIVE ORGANS

Heat stress affects mustard at cellular to whole plant level.

A. Effect on Male Reproductive System - Most Sensitive:

Pollen is most sensitive. At >29°C:

- Pollen viability reduced from 90% to 20-30%

- Anther indehiscence - anther does not open

- Tapetum layer degenerates early - pollen starvation

- Pollen tube does not germinate on stigma

Result: Flower is healthy but no seed formation - called *Pollen sterility*.

B. Effect on Female System and Fertilization:

- Stigma becomes dry, less receptive

- Ovule abortion

- Fertilization failure even if pollen is healthy

- Flower drop 40-60% in heat stress

C. Physiological and Biochemical Changes:

1. *Photosynthesis failure:* High temp damages chlorophyll, reduces Fv/Fm ratio. Rubisco enzyme activity reduced by 50% at 35°C. Leaves produce less sugar.

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2. Respiration increases: Plant burns stored sugars for maintenance, no sugar left for pods.

3. Oxidative stress: High ROS produced. Membrane lipid peroxidation increases, MDA content increases 3 times. Membrane becomes leaky.

4. Water relations: High VPD causes stomatal closure, canopy temperature rises further by 5-6°C. Plant goes into self-heating cycle.

5. Hormonal imbalance: ABA increases, auxin and cytokinin decrease - leads to abscission of flowers and pods.

6. Source-Sink relationship fails: Leaves cannot supply assimilates to pods. Pods become chaffy.[Superoxide][H2O2][source][sink]

EFFECT ON YIELD AND QUALITY Visible symptoms in field:

- Flowering period shortened from 25 days to 12-15 days

- Top flowers dry and shed

- Siliquae per plant reduced from 250 to 120-150

- Pod length reduced 6 cm to 4 cm

- Seeds per pod reduced 14 to 8-9

- Forced maturity - crop matures 10-15 days early, leaves remain green but pods dry - false maturity[pods]

Quantified yield loss:

- 1°C rise from 28°C to 29°C during flowering = 7-9% yield loss

- 3°C rise = 25-30% loss

- All India data: Late sown mustard [Nov 30] yields 30-35% less than timely sown [Oct 25]

Effect on Quality:

- Oil content: Normal 39-42%, under heat stress 34-36%. Every 1°C rise reduces oil by 1.2%

- Fatty acid profile changes - erucic acid increases, oleic acid decreases

- 1000-seed weight reduced from 5.5g to 3.8g

- Protein content also affected

Biochemical markers for screening:

Scientists use Membrane Thermostability Index, Chlorophyll fluorescence, Pollen germination test at 32°C in lab, and Canopy Temperature Depression to screen heat tolerant lines.

MANAGEMENT STRATEGIES FOR HEAT STRESS

A. Agronomic Management - Immediate Solution:

1. Timely Sowing: Most important. Ideal window Oct 15-30. This ensures flowering in last week of Jan when temp is <25°C. Zero-till mustard after rice saves 10-12 days and helps escape heat.

2. Irrigation Management: One light irrigation at 50% flowering reduces canopy temperature by 3-4°C and increases pollen viability by 20%. Do not give heavy irrigation.

3. Nutrient Management:

- Potash 40 kg/ha as basal - improves stomatal regulation

- Sulphur 40 kg/ha - must for mustard oil synthesis

- Foliar spray of KNO3 1% + Boron 0.2% at flower initiation

4. Mulching and Conservation Agriculture: Keep rice straw or mustard stalk as mulch. Soil temperature reduced by 2-3°C. Retains moisture.

B. Chemical and Physiological Approaches:

1. Salicylic Acid 100 ppm spray at 45 DAS - induces antioxidant enzymes

2. Thiourea 1000 ppm spray at flowering - improves source-sink and osmoprotection

3. Brassinosteroids 2 ppm - helps in pollen germination

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4. Putrescine and Proline spray - experimental but promising.*C. Breeding and Varietal Solution - Long Term:

Heat tolerant varieties developed by DRMR Bharatpur and ICAR:

- RH 1566, RH 1424, DRMR 1165-40: Can tolerate up to 32°C at flowering

- NRCHB 101, CS 56, CS 58: Suitable for late sown condition

- Pusa Mustard 30, 31: Low erucic acid + heat tolerant

Breeding traits needed: Early flowering [50 DAS], Long pod filling duration, High pollen viability at high temp, Stay-green trait, High NDVI.

Modern tools: Marker Assisted Selection for heat QTLs, CRISPR for heat shock proteins.[HSPs]

Conclusion:

Heat stress during reproductive stage is a hidden hunger in mustard. It does not kill plant but kills yield. Since mustard pollen dies at 32°C, we cannot cure after damage, only escape and tolerate.

Integrated strategy - *Timely sowing + One irrigation at flowering + KNO3 spray + Heat tolerant variety* can reduce loss by 70% and stabilize yield at 20-22 q/ha.

For future sustainable mustard production in India, we need to shift to climate-smart package combining Conservation Agriculture + Precision irrigation + Heat tolerant varieties.

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Conservation Agriculture for Sustainable Cotton Production

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Introduction

Cotton is called White Gold in India. India is the largest cotton growing country with 12.5 million hectares. Tamil Nadu, especially Tirupur - Coimbatore belt, is the textile capital and depends heavily on cotton.

But conventional cotton farming has problems:

1. Intensive tillage - soil organic carbon in TN is now <0.5%

2. High water use - 7000-8000 litres for 1 kg lint cotton

3. Residue burning - loss of nutrients

4. Monocropping - Pink bollworm, root rot, and yield decline

5. High cost - labour, diesel, pesticide cost increased 3 times in 10 years

Sustainable cotton production is needed to meet Better Cotton Initiative (BCI), organic and regenerative standards which Tirupur export companies now ask for.

Conservation Agriculture (CA) is a FAO recommended system which can produce more with less disturbance to environment. It is not a single technology, it is a full farming system.

PRINCIPLES OF CONSERVATION AGRICULTURE

CA is based on 3 interlinked principles:

Principle 1: Minimum Mechanical Soil Disturbance

Zero tillage or strip tillage only. Sowing is done without ploughing or with single pass. Soil is not inverted. This keeps soil structure, earthworms and mycorrhiza alive. In cotton, tap root can go up to 1.5m deep if soil is not compacted.

Principle 2: Permanent Organic Soil Cover*l

Soil should not be bare. At least 30% cover with crop residues or live cover crops. Cotton stalk (6-8 tons per hectare) should be shredded and kept as mulch. This reduces evaporation by 40-50%, controls weed by 50% and adds organic matter.

Principle 3: Diversification / Crop Rotation

Cotton cannot be grown year after year. Must rotate with legumes or cereals. Intercropping is also part of CA.

Example: Cotton + Blackgram (6:1), Cotton + Groundnut, Cotton - Wheat, Cotton - Chickpea system. Legume fixes 40-60 kg Nitrogen per hectare free.

These 3 principles must be followed together. If only zero tillage without mulch and rotation, it is not CA.

CA PRACTICES FOR COTTON. *A. Land Preparation and Sowing:

1. Strip Tillage: Only 10-15 cm wide strip is tilled where seed falls. Rest remains undisturbed.

2. Zero Till Planter: Special planter places seed and fertilizer through residue.

3. Bed Planting: Cotton on permanent beds, residue in furrows. Saves 30% water.

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B. Residue Management:

1. Do not burn cotton stalks. Use shredder and spread uniformly.

2. If residue is too much, use Happy Seeder type planter.

3. In rainfed areas, keep 3-4 ton mulch, rest can be composted.

C. Cover Crops and Green Manure:

Between two cotton seasons, grow short duration cover crop:

- Sunhemp - 45 days, adds 20 ton biomass

- Horse gram / Cowpea - good for Tamil Nadu rainfed

- Kill cover crop with roller crimper and sow cotton directly into it.

D. Intercropping and Rotation for TN Condition:

- Irrigated: Cotton + Onion / Cotton + Blackgram (1:1)

- Rainfed: Cotton + Greengram, Cotton + Cowpea

- Rotation: Cotton - Ragi - Cowpea (best for soil health)

- Border crop: Marigold and castor to trap bollworm

E. Water and Nutrient Management:

- Drip irrigation under mulch is the best combination. Water Use Efficiency increases from 45% to 85%.

- Fertigation: Apply 75% RDF through drip + biofertilizers (Azospirillum + Phosphobacteria)

- Foliar spray of Pink Pigmented Facultative Methylotrophs (PPFM) during drought

F. Integrated Weed and Pest Management:

Weed problem in first 2 years of zero tillage is more. Manage by:

- Mulch itself suppresses weeds

- Pre-emergence Pendimethalin + one hand weeding

- Intercrop covers empty space

Pest: Diversity reduces pink bollworm by 30% as per CICR Nagpur trial.

BENEFITS OF CA IN COTTON

1. Soil Health Benefits:

- Organic Carbon increased from 0.45% to 0.82% in 3 years (CICR data)

- Water holding capacity increased by 15-20%

- Earthworm population increased 3 times

- Soil temperature reduced by 3-5 degree C in summer

2. Economic Benefits:

- Cost of cultivation reduced Rs. 8,000 - 12,000 per hectare (less tillage, less diesel, less labour)

- Net profit increased by 18-25%

- Yield stabilization: In drought year, CA cotton gave 12% more yield than conventional

3. Environmental Benefits:

- 35% diesel saving = less CO2 emission

- No residue burning = less air pollution

- Carbon sequestration: 0.3-0.5 ton C per hectare per year

- Groundwater saving: 150-200 mm per season

4. Sustainability and Market Benefits:

- Meets BCI, Regenerative Cotton Standard - Tirupur mills give premium Rs. 2-4 per kg

- Good for long-term farming, land value increases

Data from Tamil Nadu Agricultural University (TNAU): Zero till + Residue + Blackgram intercrop gave 22.5 q/ha seed cotton vs 19.8 q/ha in conventional.

CHALLENGES, SOLUTIONS AND CONCLUSION

Challenges in Adoption:

1. Lack of suitable machinery - Zero till planter not available in all villages

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2. Initial weed problem - farmers fear yield loss

3. Residue management - shredder cost high

4. Knowledge gap - extension workers still teach intensive tillage

5. Mindset - "Without ploughing, crop won't come" belief

Solutions:

1. Custom Hiring Centres: Govt gives 50% subsidy for CA machineries through Sub-Mission on Agricultural Mechanization (SMAM)

2. Farmer Producer Organizations (FPO) in Tirupur can buy one set for village

3. Training by Krishi Vigyan Kendra (KVK) - TNAU conducts CA training every month

4. Start small: Try CA in 0.5 acre first year, expand next year

5. Govt schemes: NMSA, PKVY support CA with Rs. 5000/ha incentive

Future Scope:

With climate change, CA is the only way. Integration of CA + Precision Farming + Drone spraying is next step for cotton in Tamil Nadu. Export buyers from Europe now ask for carbon footprint data, CA cotton can provide that.

Conclusion:

Conservation Agriculture is not just technology, it is a mindset change from soil exploitation to soil nurturing. For sustainable cotton production, CA gives triple benefits - Profit to Farmer, Health to Soil, and Premium to Textile Industry. Especially for Tirupur region where cotton sustainability is directly linked to garment export, CA is the future.

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Production Risk Under Natural Farming

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1.Introduction

Natural farming is an ecological approach to agriculture that aims to reduce dependence on purchased external inputs and make greater use of locally available farm resources. It emphasizes soil cover, biological activity, crop diversity, recycling of biomass, natural pest-management methods and efficient use of water. In India, natural farming is commonly associated with practices such as Beejamrit, Jivamrit, mulching (Acchadana), Whapasa and botanical or biological plant protection. ICAR describes natural farming as an approach using environment-friendly inputs and practices to improve soil health, agro-biodiversity and self-sustaining production systems.

2. Meaning of Production Risk

Production risk refers to uncertainty in the quantity and quality of farm output. Crop production is influenced by rainfall, drought, soil moisture, pests, diseases, weeds and other environmental conditions. A farmer therefore cannot always predict the exact harvest at the beginning of a season. Production risk becomes especially important when a farm depends heavily on a single crop or a single production input.

3. Production Risk under Natural Farming

Natural farming approaches production risk through ecological management rather than depending only on purchased inputs. Soil cover, biomass recycling, crop diversity and integrated enterprises can help spread or reduce the effects of individual production failures. However, natural farming does not eliminate risk. Its performance varies with crop, soil, climate, management skill and availability of local resources. Therefore, risk reduction should be understood as improving resilience and stability rather than guaranteeing a particular yield.

4. Main Sources of Production Risk

Risk Factor	Possible Effect on Production
Drought / irregular rainfall	Moisture stress, reduced crop growth and yield variability.
Pests and diseases	Crop damage and reduction in marketable produce.
Weeds	Competition for water, nutrients, light and labour.
Poor soil condition	Lower productivity and inefficient use of available resources.
Dependence on one crop	Failure of the main crop can affect a large share of farm output.

5. Natural Farming Practices that Address Production Risk

The major natural farming practices described in the reference material have different economic and

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production roles. Their combined use can create a more diversified and resource-recycling farm system.

Practice	How It Is Used	Risk-Related Role
Mulching (Acchadana)	Maintain soil cover using suitable biomass.	Conserves moisture, suppresses weeds and may reduce irrigation and labour requirements.
Jivamrit / bio-formulations	Use farm/local resources for preparation where appropriate.	May reduce dependence on purchased external nutrient inputs.
Mixed cropping / intercropping	Grow more than one crop in the same production system.	Uses space efficiently and spreads production risk across crops.
Crop-residue recycling	Return useful biomass to the farm system.	Converts farm biomass into a useful resource and reduces waste.
Livestock integration	Combine crops with livestock and use available farm resources.	Provides manure and additional products, creating diversified income.
Botanical / biological protection	Use ecological plant-protection approaches when technically suitable.	Can reduce reliance on some synthetic plant-protection products.

6. Flow Chart: From Risk to Resilience

PRODUCTION RISK

↓

SOIL COVER & BIOMASS + CROP DIVERSITY + INTEGRATED FARM

↓

GREATER RESILIENCE

Environmental uncertainty can be addressed through ecological practices, diversified production and reduced dependence on a single component.

7. Role of Crop Diversification

Crop diversification is one of the important pathways through which natural farming can spread production risk. Different crops may respond differently to the same weather or pest conditions. With mixed cropping or intercropping, poor performance of one crop does not necessarily mean complete failure of the whole cropping system. Diversification can also provide several possible sources of revenue and can reduce the financial impact of failure in one crop.

8. Soil Health, Moisture and Long-Term Stability

Regular soil cover, biomass recycling and reduced chemical dependence can support soil biological activity and conservation of soil moisture. Better soil condition may lower some long-term production risks. The reference material emphasizes that the actual benefit depends on local conditions; therefore, farmers should observe crop performance and maintain farm records over several seasons.

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9. Production Risk Management: A Farm-Level Framework

Effective risk management requires the farmer to identify major hazards, choose suitable practices, observe results and modify management when necessary. Natural farming can provide several tools, but each tool should be selected according to local conditions.

STEP 1: IDENTIFY → STEP 2: DIVERSIFY → STEP 3: MONITOR → STEP 4: IMPROVE

Observe • Record • Compare • Adapt

10. Risk Reduction through Integrated Farm Enterprises

Natural farming is often practiced together with crops, trees, livestock and recycling of farm resources. Integrated farming can provide more than one production component and can create income at different times of the year. For example, crop residues may become a useful farm resource, while livestock can contribute manure and additional products. Such integration can spread the consequences of failure in any one component.

11. Production Risk and Farm Income

Production risk is closely connected with farm income because changes in output affect the quantity available for sale. Natural farming may influence income through lower expenditure on some purchased inputs, diversification, recycling of resources and potentially more stable production. However, profitability should be judged using net returns rather than yield alone. Labour, training, livestock maintenance and preparation of farm-made inputs still have economic value and should be included in calculations.

12. Evidence and Practical Interpretation

The reference material cites an ICAR case from Krishna district in which a farmer shifted from chemical-intensive agriculture to Zero Budget Natural Farming. The reported experience included a relatively small decline in rice yield along with a bonus price for the grain. This illustrates that farm performance depends on more than yield: production cost and the price received also affect profitability. A premium price should not be assumed without evidence from the local market.

13. Major Challenges during the Transition

Challenge	Why It Matters for Production Risk
Transition period	Yields may vary initially; training and changes in farm management may be needed.
Labour requirement	Mulching, residue management, preparation of inputs and manual weed management can require labour.
Knowledge and skill	Incorrect preparation or inappropriate application of inputs can reduce effectiveness.
Location-specific performance	Results differ across crops, soils and climates; fixed expectations may be misleading.
Market linkages	A better price is possible only when suitable consumers or organized markets recognize product quality.

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14. Measures to Improve Production Risk Management

Measure	Practical Purpose
Farmer training	Provide training, demonstrations and scientific advisory support so that practices are applied correctly.
Diversification	Promote suitable crop diversification, intercropping and integrated farming systems.
Farm records	Record input cost, labour, yield, selling price and net returns to compare performance.
Efficient resource use	Use locally available biomass and livestock resources efficiently without compromising animal welfare or soil fertility.
Local experimentation	Test practices under local soil, climate and crop conditions instead of assuming identical results everywhere.
Multi-season evaluation	Use observations across several seasons before drawing conclusions about productivity and profitability.

15. Key Takeaways

BUILD RESILIENCE • DIVERSIFY • RECORD & REVIEW

Build resilience: Protect soil, recycle biomass and use local resources.

Diversify: Spread production risk across crops and integrated enterprises.

Record and review: Track cost, labour, yield and returns over several seasons.

16. Conclusion

Production risk is an important challenge in agriculture because farm output is affected by uncertain environmental and biological conditions. Natural farming can help manage this risk by emphasizing soil cover, biomass recycling, crop diversity, ecological plant protection and integrated farm enterprises. These approaches can reduce dependence on a single crop or external input and may support more stable production. At the same time, natural farming is not a universal guarantee against crop failure. Outcomes vary according to climate, soil, crop, management skill and local resource availability. Therefore, production risk under natural farming should be managed through appropriate training, diversification, careful observation, farm records and location-specific, multi-season evaluation.

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Crop Rotation and Soil Management

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1.Introduction

Agriculture depends mainly on the quality and productivity of soil. Soil provides plants with water, nutrients, air and physical support for growth. Continuous cultivation of the same crop can reduce soil fertility, increase pest and disease problems, and cause deterioration of soil structure. Therefore, proper soil management practices are essential for maintaining soil health and achieving sustainable crop production.

Crop rotation is one of the important practices used for maintaining soil fertility and improving agricultural productivity. It involves growing different crops in a planned sequence on the same piece of land over different seasons or years. When crop rotation is combined with proper soil management practices such as addition of organic manures, balanced fertilizer application, erosion control and efficient irrigation, it helps maintain soil health for a long period.

1. CROP ROTATION

Definition

Crop rotation is the **systematic growing of different crops on the same piece of land in a definite sequence over a period of time**.

For example: **Year 1 – Rice → Year 2 – Pulses → Year 3 – Groundnut**.

Instead of growing the same crop continuously, different crops with different nutrient requirements are included in the cropping sequence.

2. Principles of Crop Rotation

1. Include Leguminous Crops

Leguminous crops such as green gram, black gram, cowpea and groundnut can improve soil nitrogen through biological nitrogen fixation.

2. Avoid Growing the Same Crop Continuously

Continuous cultivation of the same crop may lead to depletion of particular nutrients and increase pest and disease problems.

3. Alternate Deep and Shallow Rooted Crops

Deep-rooted crops utilize nutrients and water from deeper soil layers, while shallow-rooted crops mainly use the upper soil layers. Their rotation helps in better utilization of soil resources.

4. Include Crops with Different Nutrient Requirements

Heavy-feeding crops should be followed by crops that require comparatively fewer nutrients.

5. Include Green Manure Crops

Green manure crops such as sunhemp and dhaincha can be incorporated into the soil to increase organic matter and improve soil fertility.

6. Consider Local Climate and Soil

The crops selected for rotation should be suitable for the local soil, climate, irrigation facilities and market conditions.

3. Examples of Crop Rotation

- Rice → Pulses → Rice
- Maize → Groundnut → Pulses
- Cotton → Sorghum → Green gram

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• Wheat → Gram → Fodder crop
• Maize → Cowpea → Vegetables

The exact rotation depends on soil type, rainfall, irrigation availability and farming conditions.

4. Importance of Crop Rotation

Maintains Soil Fertility

Different crops remove different nutrients from the soil. Crop rotation helps maintain a better nutrient balance.

Improves Soil Structure

Different root systems add organic residues to the soil and improve soil structure.

Controls Pests and Diseases

Changing crops interrupts the life cycle of many crop-specific pests and diseases.

Controls Weeds

Different crops have different growth patterns and cultivation practices. This helps suppress and control weeds.

Improves Nitrogen Availability

Leguminous crops fix atmospheric nitrogen through their association with Rhizobium bacteria.

Reduces Soil Erosion

Including crops with good ground cover reduces the impact of raindrops and helps protect the soil surface.

Improves Water Use

Different crops have different water requirements and rooting depths, allowing better utilization of available soil moisture.

Increases Crop Productivity

Healthy soil and reduced pest and disease pressure can improve crop growth and yield.

5. SOIL MANAGEMENT

Definition

Soil management is the proper use and management of soil resources to maintain or improve soil fertility, productivity, structure and overall soil health. The main aim of soil management is to maintain productive soil while preventing degradation.

6. Objectives of Soil Management

• To maintain soil fertility.

• To improve soil structure.

• To conserve soil moisture.

• To prevent soil erosion.

• To maintain soil organic matter.

• To improve nutrient availability.

• To control soil degradation.

• To maintain long-term crop productivity.

7. Important Soil Management Practices

1. Addition of Organic Manures

Organic manures such as farmyard manure (FYM), compost, vermicompost and green manure improve soil physical, chemical and biological properties. They increase organic matter, improve water-holding capacity and support beneficial soil organisms.

2. Balanced Fertilization

Crops require essential nutrients such as nitrogen, phosphorus and potassium along with secondary and micronutrients. Fertilizers should be applied based on crop requirements and soil-test recommendations. Balanced fertilizer use prevents nutrient deficiencies and excessive fertilizer application.

3. Green Manuring

Green manure crops are grown and incorporated into the soil while they are still green. Examples include sunhemp, dhaincha and cowpea. Green manuring increases organic matter and improves soil fertility.

4. Soil Erosion Control

Soil erosion removes the fertile topsoil. It can be controlled by contour farming, terracing, strip cropping, cover crops, mulching, planting trees and grasses, and maintaining crop residues.

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5. Mulching

Mulching means covering the soil surface with materials such as crop residues, straw, leaves or suitable organic materials. It reduces evaporation, conserves soil moisture, controls weeds, reduces soil temperature fluctuations, protects soil from erosion and adds organic matter when organic mulch decomposes.

6. Proper Irrigation Management

Excess irrigation can cause waterlogging and salinity, while insufficient irrigation can cause moisture stress. Proper irrigation scheduling helps maintain suitable soil moisture and prevents wastage of water.

7. Drainage Management

Good drainage is important in areas where excess water accumulates. Proper drainage prevents waterlogging and helps maintain adequate air in the soil.

8. Conservation Tillage

Conservation tillage involves reducing unnecessary soil disturbance and retaining crop residues on the soil surface. It helps reduce erosion, conserve moisture, maintain soil organic matter and improve soil structure.

9. Soil Testing

Soil testing helps determine the availability of nutrients and important soil properties. Based on soil-test results, suitable fertilizers and amendments can be recommended. Soil testing promotes efficient fertilizer use and reduces unnecessary input costs.

8. Relationship Between Crop Rotation and Soil Management

Crop rotation and soil management are closely related. Crop rotation is itself an important soil management practice.

- Maintain soil fertility.
- Increase organic matter.
- Improve nutrient cycling.
- Reduce pest and disease problems.
- Improve soil structure.
- Reduce erosion.
- Improve water-use efficiency.

For example, including a pulse crop after a cereal crop can help improve nitrogen availability and break pest and disease cycles.

9. Advantages of Combining Crop Rotation with Soil Management Sustainable Soil Fertility Continuous nutrient removal is reduced and nutrient cycling is improved.

Better Soil Health

Organic matter, microbial activity and soil structure can be improved.

Higher and Stable Productivity

Healthy soil provides better conditions for root growth and crop development.

Reduced Pest and Disease Problems

Crop diversity can interrupt pest and disease cycles.

Reduced Dependence on Chemical Inputs

Good crop rotation and biological processes can help reduce the need for excessive fertilizers and pesticides.

Better Moisture Conservation

Organic matter and crop residues improve water infiltration and moisture retention.

Environmental Protection

Good soil management reduces erosion, nutrient losses and degradation of agricultural land.

10. CONCLUSION

Crop rotation and soil management are essential components of sustainable agriculture. Crop rotation helps maintain nutrient balance, reduce pest and disease problems, control weeds and improve soil productivity. Proper soil management practices such as organic manure application, balanced fertilization,

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green manuring, mulching, soil conservation, proper irrigation and soil testing help maintain healthy and productive soil.

Therefore, farmers should adopt suitable crop rotations along with scientific soil management practices according to their soil, climate and cropping conditions. Proper management of soil today will help maintain agricultural productivity and food security for future generations.

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Carbon Sequestration Potential of Natural Farming

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1.Introduction

Carbon sequestration is the process by which atmospheric carbon dioxide (CO_2) is captured and stored in vegetation, soil organic matter and other carbon pools. Agriculture can either release greenhouse gases or help store carbon, depending on the management practices followed. Natural farming is an ecological approach that aims to reduce dependence on external chemical inputs and strengthen biological processes within the farm. Practices such as maintaining soil cover, using crop residues, integrating diverse crops, recycling farm biomass and encouraging soil microorganisms can contribute to building soil organic carbon.

The carbon sequestration potential of natural farming is therefore closely linked with improvements in soil organic matter, plant biomass and long-term soil health. When carbon enters the soil through roots, residues and microbial activity and remains stored for a sufficiently long period, natural farming can contribute to climate-change mitigation while also supporting sustainable crop production.

2. Natural Farming and Carbon Sequestration

Natural farming emphasizes locally available biological resources, minimum disturbance of soil, biodiversity and recycling of organic materials. Healthy soils contain carbon in several forms, including living organisms, decomposing residues and stable organic matter. Natural farming can increase the amount of carbon entering these pools by promoting continuous plant growth and returning biomass to the soil.

The effect is not identical on every farm. Carbon storage depends on soil type, climate, crop, duration of management, water availability and the specific practices adopted. Consequently, carbon sequestration should be assessed over time using appropriate soil and biomass measurements rather than assuming a fixed carbon gain for all natural farms.

3. Major Practices that Enhance Carbon Storage

3.1 Crop Residue Recycling

Returning crop residues to the field adds carbon-containing organic material to the soil. Residues provide food for soil organisms and, as they decompose, part of the carbon can become incorporated into soil organic matter.

3.2 Cover Crops and Mulching

Living cover crops protect the soil surface, produce additional biomass and contribute carbon through roots. Mulching with plant residues reduces direct exposure of soil to heat and rain and supplies organic material as it decomposes.

3.3 Crop Diversification

Crop rotation, intercropping and inclusion of different plant species can increase the diversity and continuity of root inputs. Different rooting patterns may distribute organic carbon through different soil layers and support a wider range of soil organisms.

3.4 Reduced Soil Disturbance

Reducing unnecessary soil disturbance can help protect soil aggregates and organic matter. Lower

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disturbance also supports soil biological activity and may reduce the rapid exposure of protected organic carbon to decomposition.

3.5 Use of Farm-Based Biological Inputs

Natural farming may use preparations and biomass produced within the farm. Their main contribution to carbon storage is associated with improving biological activity, plant growth and organic matter cycling when they are integrated with broader soil-management practices.

3.6 Agroforestry and Perennial Components

Trees and perennial plants store carbon in woody biomass, roots and soil. Integrating suitable trees with crops or maintaining perennial vegetation can create additional above-ground and below-ground carbon pools.

4. Carbon Pools in Natural Farming

Carbon in a natural farming system can be stored in several pools. Above-ground biomass includes stems, leaves and branches. Below-ground biomass includes roots. Soil organic carbon is particularly important because soil can store substantial quantities of carbon. Stable organic matter associated with soil minerals and aggregates can remain in the soil for relatively long periods. Farm trees and perennial vegetation can provide additional long-term storage.

The movement of carbon can be viewed as a cycle: plants absorb CO_2 through photosynthesis, carbon is transferred to plant tissues and roots, residues enter the soil, microorganisms decompose part of the material, and some carbon becomes stabilized in soil organic matter. A portion is eventually returned to the atmosphere through respiration and decomposition. Effective management aims to increase the amount retained in relatively stable pools while maintaining healthy nutrient cycling.

5. Factors Affecting Carbon Sequestration Potential

• Soil properties: Texture, mineral composition, pH, drainage and existing organic carbon strongly influence carbon storage.

• Climate: Temperature and rainfall affect plant productivity and the rate at which organic materials decompose.

• Crop and root system: Crops with high biomass production and extensive root systems can provide greater carbon inputs.

• Duration of practice: Soil carbon changes are generally gradual, so long-term management and repeated measurements are important.

• Biomass management: Returning residues, maintaining mulch and reducing unnecessary biomass removal can increase carbon inputs.

• Water and nutrient management: Adequate resources are necessary for plants to produce biomass and transfer carbon into soil.

6. Methods for Assessing Carbon Sequestration

Carbon sequestration should be evaluated using measurable indicators. Soil organic carbon can be determined by collecting soil samples at defined depths and measuring carbon concentration. Bulk density is also needed when converting concentration into carbon stock per unit area. Repeated measurements over several years can indicate changes in soil carbon stocks.

Plant biomass and tree biomass can be estimated using field measurements and appropriate biomass equations. Farm records can also help quantify residue inputs and changes in management. For meaningful comparisons, measurements should use consistent sampling depths, locations, seasons and analytical methods. Greenhouse-gas accounting can complement soil measurements by considering emissions associated with farm operations and inputs.

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7. Benefits of Carbon Sequestration through Natural Farming

• Improves soil organic matter and supports soil structure.

• Enhances water-holding capacity and can improve resilience to periods of moisture stress.

• Supports soil microbial diversity and nutrient cycling.

• Reduces the need for some external agricultural inputs when locally available resources are effectively recycled.

• Helps protect soil from erosion through continuous cover and residue management.

• Can contribute to climate-change mitigation by storing carbon in soil and biomass.

8. Challenges and Limitations

Carbon sequestration is influenced by local conditions, and increases in soil carbon are not guaranteed under every natural farming system. Soil carbon can also decline if biomass is removed, decomposition is rapid or management changes. Measuring soil carbon accurately requires careful sampling and laboratory analysis. In addition, carbon stored in soil can be vulnerable to disturbance or changes in climate and management. Therefore, claims about carbon sequestration should be based on site-specific, long-term measurements.

Natural farming should also be evaluated as a complete farming system. Carbon storage is only one sustainability indicator; productivity, profitability, soil fertility, water use, biodiversity and farmer livelihoods are also important when assessing agricultural practices.

9. Conclusion

Natural farming has the potential to support carbon sequestration by increasing plant biomass, maintaining soil cover, recycling residues, diversifying crops, reducing unnecessary soil disturbance and integrating perennial vegetation. These practices can increase carbon inputs to soil and biomass while improving soil health. However, the actual amount of carbon stored varies with environmental conditions and management history. Long-term field measurements of soil organic carbon, biomass and greenhouse-gas emissions are essential for accurately determining the carbon sequestration potential of natural farming.

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