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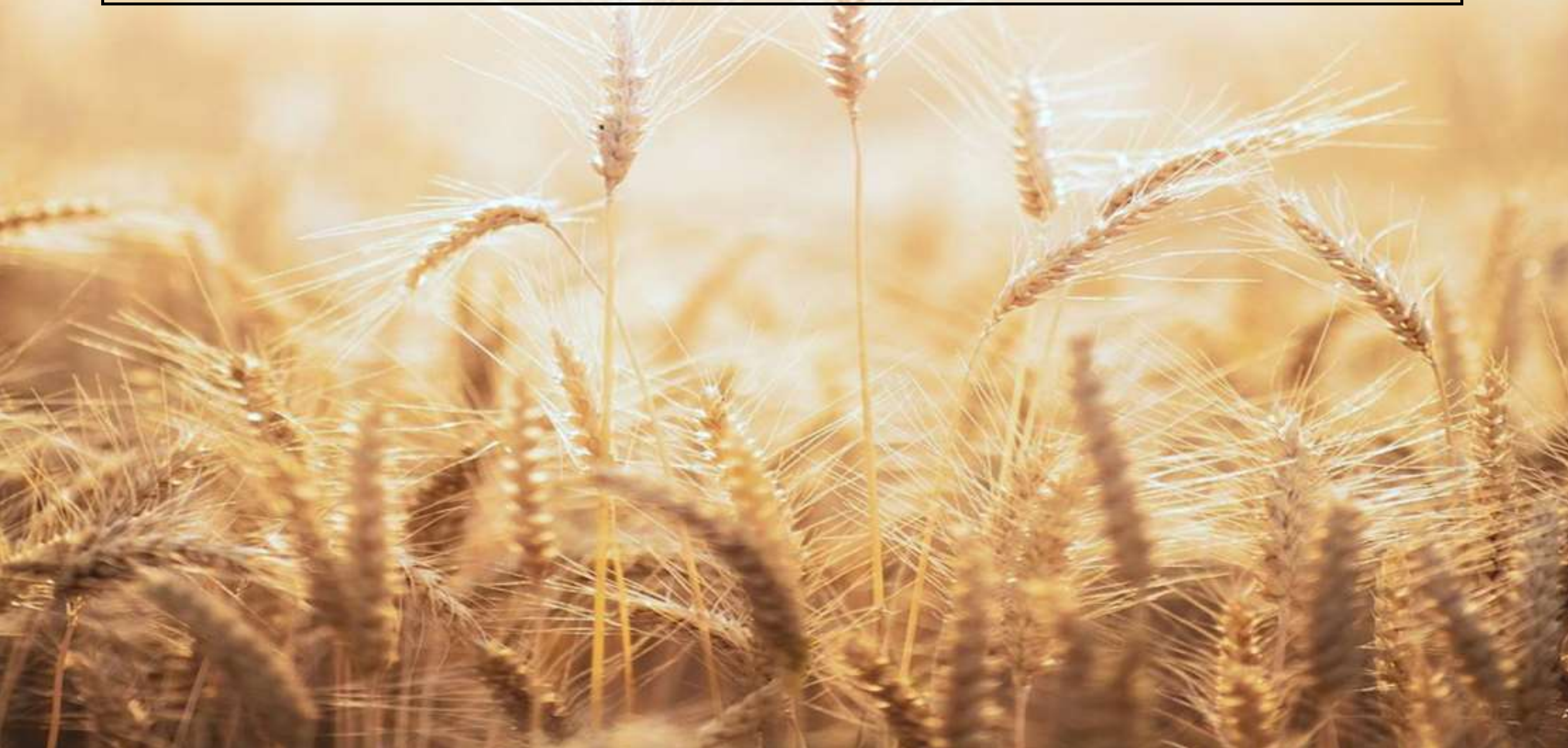

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Mobile Apps for Real Time Agronomic Decision Making

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The use of digital technology in agriculture is transforming the way farmers decide, run, and implement their operations. Real-time agronomic decision-making mobile applications have become essential tools that give farmers immediate, data-d-riven insights. The applications harness technologies like Artificial Intelligence (AI), Global Positioning System (GPS), remote sensing, and weather forecasting to give accurate and timely recommendations that are specific to local conditions. Some of the key functionalities are pest and disease diagnosis using image recognition, individualized crop calendars, localized input recommendations, and monitoring market prices. By providing site-specific, actionable guidance, these products considerably increase productivity, lower input expenses, and assist in sustainable agriculture practices. Moreover, voice support inclusion and regional language availability make them accessible to a broad range of user groups, including low-literacy farmers. Live expert advice also contributes to their efficiency by providing individualized solutions to field-level problems. With climate uncertainty and market volatility posing ongoing threats to conventional farming practices, mobile agronomic apps are also playing a vital role in promoting climate-resilient, low-cost, and knowledge-based farming practices.

Introduction

Contemporary agriculture is confronted with various issues, such as climate uncertainty, decreasing natural resources, and increasing input prices. These intricacies require timely, precise decision-making to maximize crop output and promote sustainable agriculture. Farmers traditionally used personal

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experience, peer-to-peer informal knowledge, or government extension services for advice. These traditional practices mostly lack real-time, site-specific guidance-particularly at times of critical crop growth stages or under unexpected adversity such as pest attacks or spasmodic weather conditions.

Here, mobile applications (apps) have become inimitable instruments for revolutionizing the way agricultural choices are being made. Capitalizing on advances in digital technology, these apps offer farmers immediate access to agronomic advisories specific to their particular crop, location, and prevailing field conditions. Facilities like weather forecasting, soil health analysis, detection of pests and diseases, and fertilizer advice enable farmers to make informed decisions at every step-from land preparation and planting to crop maintenance and harvesting. Apps also provide easy access to market prices, government programs, and financial services. By filling the information gap, mobile agronomic apps not only increase profitability and productivity but also support climate-resilient and sustainable farming, particularly for smallholder and last-mile farmers. Laso Bayas *et.al.*2020.

3. Advantages of Real-Time Agronomic Apps

Mobile agronomic apps are revolutionizing conventional farming by closing the technology-agriculture gap. These mobile apps enable farmers to be equipped with accurate, real-time information, which makes informed decision making possible. The following are the key advantages that emphasize the significance of incorporating mobile apps into contemporary farming:

1. Timely Decision Support

One of the most important advantages of agronomic apps is they can offer real-time decision-making support. By receiving on-time information on sowing dates, irrigation schedules, pest management actions, and harvesting times, farmers can undertake operations at their best times. This maximizes crop performance and minimizes the danger of losses on account of delayed or ill-informed interventions. Ogunti *et.al.*2018.

2. Location-Specific Recommendations

Through GPS, weather forecasting, and satellite imagery, these apps provide location-specific information addressing each farm's specific situation. They provide information about soil health, weather variations, and pest infestation particular to a farmer's specific location. This makes it possible for tailored solutions like site-specific fertilizer schedules, irrigation requirements, and pest management methods—leading to more intelligent use of resources and improved yields.

3. Lower Input Costs

Agronomic apps advise farmers on the correct type, amount, and time of input application. From fertilizers to pesticides to irrigation, precise suggestions prevent overuse, prevent wastage, and eliminate avoidable costs. Not only is this cost-reducing for production, but also it reduces the impact on the environment from chemical runoff and excess input usage.

4. Pest and Disease Management

Sophisticated mobile technology with AI and image recognition enables farmers to identify pests and diseases at an early stage simply by taking images of the infested crops. The app identifies the problem and recommends field-based, actionable solutions. Early intervention prevents infestation spread, maintaining crop health and productivity.

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5. Market Linkage and Price Forecasting

Agronomic apps are also used as market intelligence platforms. By offering current price directions, buyer contacts, and marketing advice, they equip farmers to sell their crops at fair prices. Transparency lowers middlemen reliance and improves farmers' negotiating strength.

6. Climate-Resilient Farming

In the age of climate change, these apps are crucial to resilience. They assist farmers in coping with changing weather patterns by suggesting drought-resistant crops, shifting planting dates, and providing early warnings for bouts of extreme weather. This anticipatory guidance enhances the farm's resilience to climatic shocks. Mendes *et.al.*2020

Source: https://dribbble.com/shots/Agriculture-App

4. Leading Mobile Apps in Agronomic Decision-Making (India & Global)

App Name	Provider	Key Features
Kisan Suvidha	Govt. of India	Weather, market prices, crop advisory, use of pesticides
m Kisan	NIC, Govt. of India	SMS-based advisory in local languages
Plantix	PEAT GmbH (Germany/India)	Pest & disease diagnosis through AI-based photos
Iffco Kisan App	IFFCO	Market prices, news, weather, personalized advice
Agri App	Agri App Technologies	Agronomy tips, e-commerce, soil test support
Crop In Smart Farm	Crop In Technology	Real-time farm monitoring and crop analysis for businesses
Farm Rise	Bayer	Personalized agronomy advice for Indian farmers
e Sagu	IIIT Hyderabad	Expert advice through uploading of crop photos
Sowing App	A Smart Tool for Precision Agriculture	timing, method, and management of crop sowing.

4. Functional Features of Contemporary Agronomic Apps

Contemporary agronomic apps are holistic platforms that combine several digital technologies to cater to the practical requirements of farmers. These apps are not only intended to supply real-time decision support but also to maximize efficiency, sustainability, and profitability through the practice of smart farming. The following features are the backbone of these potent devices:

1. AI & Image Recognition

One of the biggest breakthroughs in agronomic technology is the alignment of Artificial Intelligence (AI) with image identification. With a smartphone camera, the farmer simply snaps a photo of infected or pest-infested plants. The AI identifies the problem-whether it is fungal infection, pest damage, or lack of nutrients-and delivers instantaneous, scientifically proven advice. This greatly eliminates the necessity of on-site expert diagnosis and saves precious time.

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2. GPS and Geo-Tagging

By combining GPS functionalities, such apps provide precision farming functionality by mapping out individual farms. Site-specific advice to farmers is provided based on climatic and geographic factors. Geo-tagging provides location-based pest forecasts, crop suggestions, and location-targeted nutrient management plans—ensuring interventions are timely and targeted at local conditions.

Source: https://www.growingproduce.com

3. Weather Forecasting

Weather volatility is capable of affecting farming extensively. Hyper-local weather forecasts provided every hour, day, or week by most agronomic apps are accompanied by warning signs for unfavorable conditions like storms, drought, and unseasonal rainfall. This enables farmers to schedule field operations, ensure crop protection, and avoid losses from unforeseen climatic incidents.

4. Crop Calendar and Task Manager

A crop calendar is integrated into the app in digital form, which informs farmers about every phase of the growing stage of the crop. It provides reminders and scheduling features for preparing land, sowing seeds, irrigation, use of fertilizers, pesticides, and harvesting. The timely alerts avoid mistakes and streamline farm activities.

5. Voice Support & Regional Languages

To promote digital inclusivity, many apps now include voice commands and multi-language interfaces covering major Indian languages. This feature is crucial for reaching semi-literate and illiterate farmers, ensuring they can understand and utilize the technology effectively without barriers.

6. Expert Chat or Helpline

Immediate contact with agronomists and agricultural specialists is facilitated by in-app chat, audio, or video call functionality. Such direct support guarantees that farmers get tailored solutions to specific field issues, building confidence in the app and minimizing reliance on physical extension services.

5. Case Studies and Field Impact

A. Plantix in Maharashtra

A cotton farmer in Jalgaon, Maharashtra, was hit by a virulent pest infestation that led to leaf yellowing and curling-symptoms he was not familiar with. He just took a photo of the infected crop with the Plantix app, and the app instantly identified it as cotton leaf curl virus. The app also prescribed precise remedial steps, the right pesticide and at what quantity. By acting quickly, he managed to salvage more than 60% of his crop, aside from preventing unnecessary use of pesticides, hence reducing costs and environmental damage.

B. Sowing App in Andhra Pradesh

With the help of Microsoft and ICRISAT, an Sowing App using AI was unveiled for groundnut farmers in Andhra Pradesh. The app suggested scientifically determined sowing dates based on past weather history, soil moisture conditions, and actual-time forecasts. Farmers using the app's recommendations recorded an additional 30% yield. On-time sowing and improved input planning were major factors behind this development, solidifying the worth of predictive decision tools for rainfed farming areas. Sennuga *et.al.*2023.

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C. e-Sagu in Telangana

Weekly digital advisories to farmers were offered through the e-Sagu project by integrating images, remote sensing, and knowledge. Farmers observed healthier crops, improved disease management, and a 25% average reduction in input expenses, ensuring the long-term value addition of digital extension services to semi-arid regions

6.Challenges in Adoption

Challenge	Solution
Low smartphone penetration in rural areas	Provide offline versions or low-data usage models
Digital illiteracy among elderly farmers	Community training sessions, use of audio/voice support
Language barriers	Ensure multilingual support with localized content
Data privacy concerns	Implement data protection frameworks and user consent
Connectivity issues	Enable offline sync and app caching features

Conclusion

Mobile apps have become potent drivers in agriculture today, revolutionizing farm-level decision-making. Through real-time access, data-driven precision, and operational flexibility, these apps enable farmers to react quickly to agronomic issues. Beyond yield and income improvement, their benefits include climate resilience, input efficiency, and sustainable land management. For last-mile and smallholder farmers, mobile apps are not just an added convenience but an essential survival and development tool in an evolving agricultural environment.

Way Forward

To unlock the transformative power of mobile agronomic apps, strategic efforts must be made across several fronts. Policy support is vital, with governments facilitating digital inclusion through favorable regulations, innovation grants, and public-private collaborations. Localization ensures accessibility by offering content in regional languages, using simple text, voice assistance, and pictograms to support low-literacy farmers. Integration with local agri-input vendors, weather services, financial institutions, and market systems will create a comprehensive ecosystem. Finally, research and feedback loops—driven by user insights, big data, and on-field trials—are essential for continuous app refinement and practical utility.

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Role of Ornamental Fruit Trees: A New Frontier in Agri - preneurship in India

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India's agricultural sector is at a turning point. While traditional farming continues to dominate, young agri-preneurs are exploring alternative, profitable, and sustainable models. Among the emerging trends is the cultivation and commercialization of ornamental fruit trees - a niche that merges horticulture, landscaping, eco-tourism, and high-value retail. With rising demand for aesthetic landscapes, urban green spaces, and edible ornamental varieties, these trees are gaining attention not only for their beauty but also for their economic and ecological value.

What are Ornamental Fruit Trees?

Ornamental fruit trees are species or varieties that bear edible or inedible fruits while exhibiting highly decorative features such as Attractive flowers (e.g., Cherry blossom), Unique foliage or branch structure (e.g., Japanese Maple), Vibrant fruit color or shape (e.g., Ornamental pomegranate, crab apple), Compact or bonsai-like growth habit. These trees are increasingly used in Urban landscape architecture, Home gardens and balconies, Agro-tourism ventures, Boutique fruit nurseries, and Premium indoor/outdoor décor setups.

Agri-preneurship Potential: Why It Matters?

Ornamental fruit trees represent a hybrid opportunity - blending agriculture, art, technology, and business. The following are key ways this can promote agri-preneurship:

1. High-Value Niche Market

These trees command premium prices due to their aesthetic appeal. Urban households, luxury resorts, cafes, government landscaping contracts, and gated communities are willing to pay a premium for beautiful, low-maintenance, fruit-bearing trees.

2. Urban and Peri-Urban Farming

Micro-scale cultivation in pots, rooftops, or small patches appeals to urban agri-preneurs. Varieties like dwarf citrus, mini pomegranates, and colorful guavas

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are ideal for urban gardens, enabling small-space entrepreneurs to enter the market.

3. Sustainable Eco-Tourism

Agri-tourism units with pathways lined with ornamental fruit trees (like flowering peaches, dwarf mangoes, etc.) offer visitors a sensory experience - smell, taste, and aesthetics—boosting tourism and hospitality-linked income.

Technological Interventions for Success

To make this a viable business, incorporating modern technology is essential. Here are the non-traditional approaches that align with new-age agri-preneurship:

A. Tissue Culture & Micropropagation

- Propagation of ornamental fruit trees via in vitro methods ensures uniformity, disease-free planting, and fast multiplication.
- Example: Tissue-cultured dwarf fig varieties and purple guavas have become popular in India and Southeast Asia.

B. Smart Nursery Management (IoT & Automation)

- Use of automated irrigation, sensor-based fertigation, and greenhouse automation boosts productivity and reduces labor.
- Controlled-environment propagation is critical for bonsai-grade ornamental fruit trees.

C. Online Sales and Digital Branding

- Direct-to-consumer (D2C) model through Instagram, WhatsApp, Flipkart, and Amazon platforms can drastically increase sales reach.
- Agri-preneurs can offer customized fruit tree gifts, subscription kits, or DIY bonsai kits.

D. AI & Image-Based Disease Detection

- Integration of mobile AI apps for disease and pest diagnosis ensures rapid decision-making and reduces plant loss.
- Affordable to small nursery owners through freemium models.

E. Value Addition via Fruit & Aesthetic Use

- Secondary revenue: Flowers and fruits can be used for natural dye extraction, edible decorations, fruit-based cosmetics, or herbal teas.

Successful Models

1. Sikkim Cherry Trail (North East India)

A successful initiative where farmers have planted flowering cherry trees along rural roads and tourism spots. Income has risen due to photo-tourism and seasonal festivals, and cherry-based cosmetics.

2. Mini Mangoes in Maharashtra

A nursery in Pune developed dwarf Alphonso and Kesar mangoes, packaged as ornamental gifts. With social media promotion, it grew to a ₹25 lakh annual turnover business within 3 years.

3. Telangana's Rooftop Citrus Project

Agri-startups collaborated with municipal bodies to promote ornamental citrus (like blood oranges) on rooftops with drip-irrigation kits and mobile monitoring. Subsidy-linked and scalable.

Table 1. Challenges & Recommendations

Challenges	Recommendations
Lack of awareness	Workshops, demo farms, KVK involvement
Initial cost of tech	Government support, SHG & FPO models
Market linkage	Digital platforms, B2B with landscape firms
Unskilled labor	Training programs under Skill India

Government Schemes to Leverage

- **MIDH (Mission for Integrated Development of Horticulture)** – for nursery setup and infrastructure.
- **Agri-Clinics and Agri-Business Centres Scheme (ACABC)** – for training and handholding agri-preneurs.
- **Startup India & PMFME** – for branding and processing initiatives.
- **State Horticulture Missions** – for exotic fruit tree support.

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Table 2. Recommended Ornamental Fruit Trees for Indian Conditions

Tree	Feature	Notes
Dwarf Guava (Pink/Purple) 	Colorful fruit, compact	High demand in balconies
Flowering Pomegranate 	Bright red flowers, small fruits	Good for dry climates
Dwarf Mango (Amrapali) 	Bonsai - like	Popular gift item
Citrus (Lemon) 	Fragrant + edible	Rooftop and indoor use
Cherry Blossom (*Prunus* spp.) 	Flower tourism	Best in North-East, Himachal
Crabapple 	Aesthetic fruits, pollinator	Temperate zones

Conclusion: A Blossoming Opportunity

The ornamental fruit tree sector is not merely about planting pretty trees - It's a tech-integrated, market-driven, climate-resilient pathway to new-age agriculture. With the right support, Indian youth can explore this space to generate employment, income, and green innovation. Agri-preneurship rooted in beauty, sustainability, and profitability is indeed the future and ornamental fruit trees can be at its heart.

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Promoting Natural Farming Techniques to Enhance Soil Health

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This bulletin discusses the place of natural farming methods in strengthening soil health and inducing sustainable agriculture. Natural farming eschews chemical inputs and uses eco-processes to rebuild soil fertility, enhance biodiversity, and enhance water holding capacity. Critical practices like bio-input application, mulching, zero tillage, and crop diversification aid in the reconstructions of soil organic matter and microbial life. With case studies and evidence from the fields, the bulletin identifies quantifiable advantages and actionable measures for larger implementation. Policy advocacy, community engagement, and technology incorporation are highlighted as key instruments to expand natural farming for sustainable and environmentally friendly food systems.

What is Natural Farming?

Natural farming is an ecological farming system that relies on locally available resources and completely avoids the use of synthetic chemicals such as fertilizers, pesticides, and herbicides. It promotes the idea of working in harmony with nature, where the farm is treated as a living ecosystem. Instead of controlling nature, natural farming encourages biological processes that regenerate and maintain soil fertility.

One of the most significant promoters of this approach, Masanobu Fukuoka, called it "do-nothing" farming- not that nothing is actually done, but that there is very little human interference. Natural farming techniques include no plowing, no application of chemical inputs, and sometimes no weeding. The philosophy centers on observing,

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respecting natural rhythms, and letting nature unfold with as little intervention as possible while providing minimal but deliberate assistance. Naresh *et.al.*2018.

How Is Natural Farming Different?

While traditional farming depends to a great extent on external chemical inputs and machinery to increase productivity, it tends to degrade the soil and decrease biodiversity. Organic farming, while more ecological, still has some external organic inputs such as composts and biopesticides. Natural farming, on the other hand, reduces all external inputs to a bare minimum, using instead in-situ, farm-prepared preparations and natural processes to preserve productivity and soil health.

Source: https://stock.adobe.com

Why Soil Health Matters

Healthy soil is the basis of a productive and resilient agricultural system. Healthy soil delivers vital nutrients to crops, holds water, sequesters carbon, and sustains a diverse microbial community. It is not only vital for food production but also for mitigating climate change and achieving long-term sustainability. But intensive farming today has caused widespread soil deterioration—eroding, nutrient loss, loss of organic matter, and decreased microbial activity. This deterioration imperils food security, water quality, and ecosystem stability. Domínguez *et.al.* 2024.

Natural Farming: A Path to Sustainability

Natural farming reinstitutes the biological activity and structure of the land. By feeding the life of the soil with organic matter, diversity in crops, and zero tillage, it rejuvenates degraded lands and encourages sustainable agricultural practices that are capable of lasting over generations. Duddigan *et.al.2023.*

Visual: Comparison Chart

Aspect	Conventional Farming	Organic Farming	Natural Farming
Inputs	Synthetic chemicals	Organic inputs	Local, natural inputs
Soil Disturbance	High (tillage)	Medium (reduced)	Minimal (no-till)
Sustainability	Low	Medium	High
Soil Health Impact	Degrades over time	Improves gradually	Regenerates actively
Cost of Production	High	Moderate	Low

Source: https://stock.adobe.com

3. Major Natural Farming Techniques

Natural farming focuses on minimal disturbance to the ecosystem as well as improving the soil's biological and structural integrity. The following methods are most important for reviving and maintaining productive soils using natural farming: Liao *et.al.* 2019.

1. Use of Bio-inputs

Natural farming substitutes chemical fertilizers with bio-inputs that are simple to prepare and cheap.

- Jeevamrutha: A fermented microbial culture prepared from cow dung, cow urine, jaggery, pulse flour, and soil. It improves microbial activity in the soil.
- Beejamrutha: A seed treatment solution that guards against soil-borne pathogens and enhances germination.
- Panchagavya: A five-cow-product-based nutrient tonic made from dung, urine, milk, curd, and ghee.

2. Mulching

Mulching is applying organic materials such as straw, dry leaves, or crop residues over the soil.

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- Organic Mulching: Retains soil moisture and provides nutrients upon decomposition.
- Soil Mulching: Refers to applying a shallow mulch of soil to shield the topsoil from erosion.

3. Crop Diversification & Rotation

Rotating various crops on a single plot minimizes the concentration of pests and diseases.

- Crop Rotation enhances soil fertility by making various nutrient requirements.
- Diversification involves planting legumes, cereals, and vegetables in rotation.

4. Zero Tillage

This method excludes plowing or soil turning. Seeds are planted directly without lifting the soil strata.

Benefits:

- Retains natural soil structure and water
- Conserves beneficial organisms such as earthworms and microbes
- Discourages erosion and compaction

5. Intercropping and Agroforestry

- Intercropping: Cultivating two or more crops together to utilize maximum space and resources.
- Agroforestry: Intercrop with shrubs and trees that give shade, biomass, and biodiversity.

Visual Suggestions:

- Soil Layering Diagram indicating root zones and microbial activity
- Mulch Application Graphic demonstrating moisture retention
- Intercropping Layout with a combination of legumes, cereals, and vegetables

4. Benefits to Soil Health

Healthy soil is the bedrock of sustainable agriculture. Natural farming revives poor soils by reviving their biological, chemical, and physical properties—giving rise to a condition in which crops grow naturally without any synthetic aids.

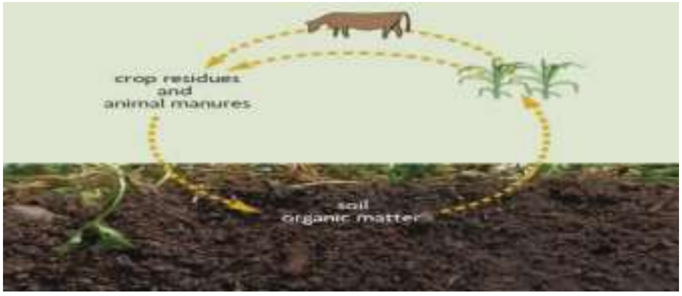
Main advantages of Natural Farming to Soil Health

1. It boosts Soil Organic Carbon (SOC)

Natural farming increases the recycling of organic matter to the soil in the form of biomass, compost, and mulch. Increased organic matter increases the level of soil organic carbon, which enhances soil structure, aeration, and fertility.

2. Stimulates Microbial Life and Biodiversity

By not using chemical inputs and by making use of bio-enhancers such as Jeevamrutha, natural farming provides beneficial conditions for beneficial microbes, fungi, earthworms, and other soil biota. These biota are the ones needed to decompose organic matter, fix nitrogen, and suppress diseases.



Source:https://geopard.tech/blog

3. Enhances Water Retention and Infiltration

Mulching by organic means and zero tillage methods minimize water run-off and encourage deeper infiltration of water. Organically rich soils retain more moisture, hence crops become more drought-resistant.

4. Restores pH Balance and Increases Nutrient Cycling

Organic inputs such as Beejamrutha and Panchagavya restore the pH balance and promote natural nutrient cycling. Microorganisms decompose organic matter and release nutrients in plant-accessible forms.

5. Minimizes Chemical Fertilizer Use

Through nutrient-dense inputs and healthy microbial populations, plants are provided with sufficient nutrition without dependence on synthetic fertilizers. This not only saves money for farmers but also eliminates soil toxicity and long-term degradation.

Evidence from Field Studies

A 3-year trial in Maharashtra and Andhra Pradesh revealed:

- 25–30% increase in soil organic carbon
- Microbial biomass was twice as much as in chemical farming fields

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- 20–40% improvement in water retention, particularly during dry periods
- pH levels remained 6.5–7.2, most when appropriate for crops

Graph: "Soil Fertility Improvement Over Time in Natural Farming Plots (2019–2022)"
(Bar graph comparing soil organic carbon, microbial count, and water retention in Year 1 vs Year 3)

6. Farmer Success Stories and Case Studies

Success stories are strong evidence of the potential for natural farming. Throughout India, there are thousands of farmers who are rejuvenating their soils, saving on input costs, and boosting yields—all while securing a sustainable future for their children. Here are two inspiring case studies:

Case 1: Andhra Pradesh Community Managed Natural Farming (APCNF)

The APCNF scheme, launched by the Government of Andhra Pradesh, is the largest natural farming program in the world. Its vision is to take 6 million farmers and 8 million hectares of agricultural land towards natural farming and become a model for other countries by 2030. Farmers under APCNF have also observed a visible change in soil structure, fertility, and crop resistance. With the application of inputs such as Jeevamrutha and zero tillage, soil organic carbon stocks in some places have risen by as much as 30% within three years.

One farmer from Anantapur district reported:

"Earlier, I relied on urea and DAP. Now, my soil is soft, teeming with life, and yields are consistent even with less water."

Major Outcomes:

- 40% less input cost
- Stability in yields in spite of sporadic rainfall
- Restoration of microbial processes and better moisture retention

This model is also empowering women at the local level via farmer cooperatives and training.

Case 2: Individual Farmer – Sangappa, Karnataka

Sangappa, Kalaburagi, Karnataka-based smallholder farmer, converted to natural farming in 2019 after years of heavy reliance on chemicals that left his soil barren and dry.

With the support of a local NGO, he implemented mulching, crop rotation, and bio-inputs. Within two years:

- Soil organic content increased from 0.4% to 1.2%
- Input costs of crops decreased by 50%
- He observed improved root growth and water-holding capacity

7.Stategies to Promote Natural Farming for Soil Health

Promoting natural farming is not only about changing agricultural practices—it's about building a supportive ecosystem that enables farmers to succeed, policymakers to lead, and communities to participate. For soil health to be truly restored on a national or global scale, coordinated strategies must focus on policy, education, technology, and local engagement. Srivastava *et.al.* 2023.

Policy Support

Government policies play a crucial role in creating a favorable environment for the adoption of natural farming.

Important strategies are:

- Subsidies for Bio-inputs: Financial subsidies or low-cost availability of Jeevamrutha, Beejamrutha, and other farm-based preparations can minimize farmers' dependence on costly chemicals.
- Training Programs for Farmers: Capacity development through agricultural extension services and rural institutions can enable farmers to comprehend and adopt natural practices with confidence.
- Certification and Market Access: Creating a reliable certification system for natural produce can create premium markets, enhancing profitability and consumer confidence.

Community Involvement

Grassroots mobilization is critical to scale natural farming.

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Mechanisms are:

Farmer Field Schools: Demonstrations and experience-sharing on farms and peer-led can empower farmers with hands-on learning and local innovation.

Local Workshops & Cooperatives: Promoting farmer groups to grow bio-inputs, exchange seeds, and share knowledge increases collective resilience and lessens individual risk.

Role of Technology

Technology can speed up the uptake and tracking of natural farming:

- Soil Health Monitoring Apps: Mobile apps are able to monitor changes in soil pH, moisture, and levels of organic carbon with the passage of time, enabling farmers to take data-driven decisions.
- Knowledge-sharing Platforms: Online forums, video tutorials in multiple languages, and agri-tech support systems can disseminate knowledge and exchange localized solutions.

Call to Action

"Healthy Soil, Healthy Food, Healthy Planet"

Natural farming is not just a method—it's a revolution. Governments, scientists, NGOs, and consumers need to unite to facilitate this sustainable shift. The future of food production hinges on caring for, rather than draining, the earth that sustains us all.

Visual Suggestion: Impact Flow Infographic

Natural Farming → Better Soil Health → Greater Biodiversity → Greater Resilience → Sustainable Yields → Food Security

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Remote Sensing and GIS: Applications in Irrigation and Soil Water Conservation Engineering

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Remote Sensing (RS) and Geographic Information Systems (GIS) are increasingly becoming useful tools in managing irrigation water and conserving soil water. As water scarcity and food needs rise, these technologies assist in monitoring soil moisture, quantifying crop water use, water stress identification, and irrigation scheduling optimization. GIS allows watershed management, erosion control, and runoff simulation using spatial data analysis. Precision agriculture combines RS and GIS for variable rate application, yield estimation, and site management. The technologies enhance water use efficiency, minimize wastage, and increase crop yields. Although challenges such as high startup costs and technical complexity are there, emerging trends like AI, IoT sensors, drones, and real-time analytics hold out future solutions for sustainable, climate-resilient, and productive agricultural systems.

Introduction:

India sustains 18% of the global population with only 2.4% of the world's land area and 4% of renewable freshwater resources. According to the UN and World Bank estimates (2022), India's population will reach nearly 1.4 billion by 2025. To meet the increasing food demand, agricultural output must rise from 208 million tons in 2000 to 350 million tons by 2025 (MoWR, 2012). Agriculture currently consumes about 80–85% of India's total water resources, but this share is expected to decline by 10–20% due to increasing domestic and industrial needs. Despite vast irrigation infrastructure, most large-scale systems operate inefficiently—only 20–40% of supplied water reaches crops. Rising water scarcity places enormous pressure on improving irrigation water use. In this context, Remote Sensing (RS) and Geographic Information Systems (GIS) have emerged as essential tools for optimizing irrigation and conserving soil water through data-driven

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monitoring, planning, and decision-making. Modern water and land resource management emphasizes sustainability and long-term ecological balance (ASCE, 1998). Remote sensing allows monitoring of soil moisture, crop health, and water stress through satellite and aerial imagery without physical contact. GIS enables spatial analysis, mapping, and planning for watershed development, erosion control, and irrigation scheduling. Together, RS and GIS technologies support site-specific, efficient, and timely resource management. Globally, regions like the Gulf Cooperation Council (GCC) also face water stress and rising food dependency. With food imports expected to grow sharply, efficient irrigation and modern agriculture systems are needed to support future food security. Implementing RS-GIS technologies in such regions not only conserves water but also reduces energy use by minimizing groundwater extraction. The Food and Agriculture Organization (FAO) reports that by 2050, global food production must increase by 70% to meet demand. To achieve this, farming must adopt smart, efficient, and technology-driven methods.

Fig: 1. Civilians is the frame for imaging, participating, assaying, tracking, and managing spatial data and data connections through desktop platforms and/ or integrated web and pall services. Sources: https://www.stcplanning.org/what-is-gis/

Precision agriculture, enabled by RS and GIS, provides real-time field insights for variable input application and improved crop yield. This paper reviews the applications of Remote Sensing and GIS in irrigation management and soil water conservation engineering. It discusses recent research (1998–2023), highlights benefits such as improved water use efficiency and soil health, and addresses current challenges including high implementation costs and data integration issues. Finally, the paper explores future trends including AI, IoT, drones, and smart irrigation systems that are reshaping sustainable agricultural practices.

Remote sensing refers to the method or technique of acquiring information regarding an object, scene, or phenomenon by analyzing data collected by an instrument without physical contact with the object, scene, or phenomena, normally using satellites or unmanned aerial vehicles. It is a method used to remotely study the physical and chemical properties of objects. Human vision, smell, and hearing are some forms of primitive remote sensing.

Geographical information system (GIS)

GIS is a "systematic arrangement of computer hardware, software, geographic data and people intended to effectively capture, store, update, manipulate, analyze and display all types of geographically referenced data/information". It may also be defined as 'a computer system able to store and utilize information defining locations on the earth's surface.

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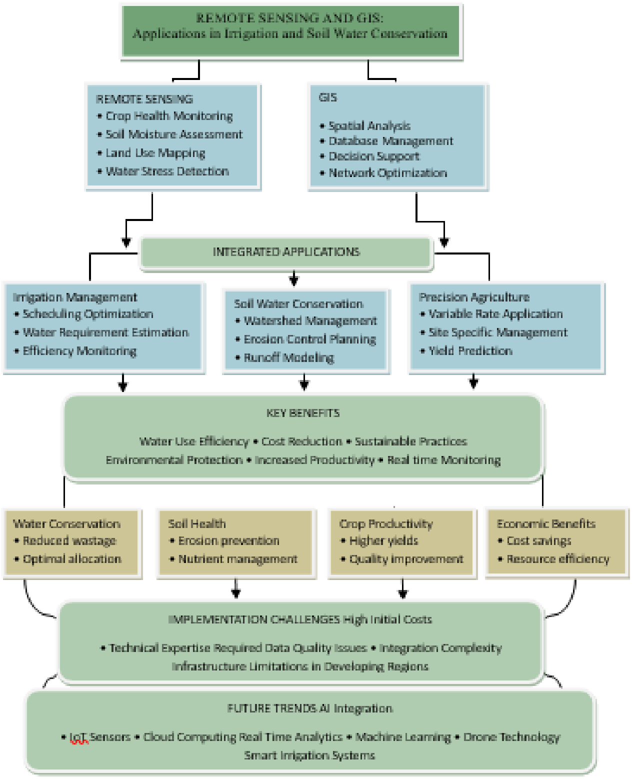
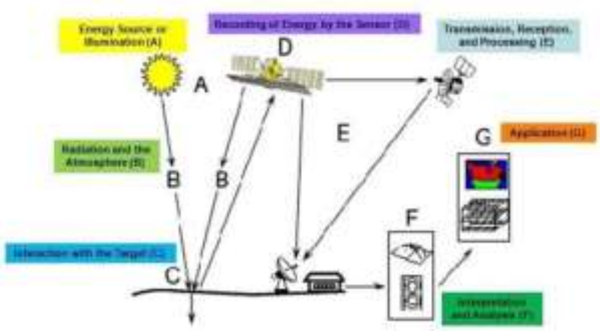


Fig: 2 Flowchart of illustrating the application of Remote Sensing and GIS in irrigation water management – from data collection to decision-making for efficient resource use.

(a)



(b)

Fig: -3. (a,b)Remote Sensing Process and the context of Geographic Information Systems (GIS)

Source:http://megaspaceit.com/gis.html,https://www.researchgate.net/figure/Remote-sensing-process 1_fig1_364165202

Irrigation Management Applications

Applications of Irrigation Management consist of maximizing water use in agriculture using tools such as remote sensing and GIS. Some important applications are scheduling the irrigation at the appropriate time, calculating crop water requirements with respect to soil and weather conditions, monitoring the efficiency of irrigation, and applying precision irrigation for water conservation in a sustainable manner along with enhanced crop yield.

a) Wetlands mapping and monitoring
b) Soil moisture estimation
c) Snowpack monitoring/ delineation of extent
d) Measuring snow thickness
e) Determining snow-water equivalent
f) River and lake ice monitoring
g) Flood mapping and monitoring
h) Glacier dynamics
i) River/delta change detection
j) Drainage basin mapping and watershed modeling
k) Irrigation canal leakage detection
l) Irrigation scheduling

Soil Water Conservation Applications

Soil water conservation targets soil moisture retention and erosion minimization. Watershed management for integrated planning, erosion control for avoiding land degradation, and GIS-based runoff modeling for designing structures such as check dams and contour bunds are the primary applications. They are important for improving water availability and ensuring sustainable agriculture.

Land Cover and Land Use

a. Natural Resource Management
b. Wildlife habitat protection/ Baseline mapping for GIS input
c. Urban expansion/ encroachment
d. Damage delineation (flood, tornado, seismic, fire)

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e. Identification of landing strips, roads, clearings, bridges, land water interface
f. Watershed Management
g. Runoff Modeling
h. Erosion Control Planning

(a) (b)

Fig: 4. (a,b) A Comparison Between IoT-Based Smart Irrigation Management System and Traditional Irrigation System

Sources:https://www.sciencedirect.com/science/article/pii/S2590123024010843 , https://allen.in/science/crop-production-and-management

Precision Agriculture Applications

Precision agriculture makes use of technology to maximize crop yields. Major applications involve variable rate applications of water, fertilizers, and pesticides as a function of field variability, site-specific management using GPS and GIS information, and prediction of yield by remote sensing and modeling. The technologies increase productivity, cut input costs, and enables sustainability.

a. Variable Rate Application
b. Site Specific Management
c. Yield Prediction
d. Climate-Smart Farming
e. Water Stress Detection
f. Decision Support Systems
g. Sensor-Based Irrigation (IoT)

Key Advantages

Water Conservation Gains through RS and GIS

1. Water Conservation: Effective monitoring and planning to conserve water resources.
2. Decreased Wastage: Selected irrigation and leak detection reduce excess water loss.
3. Efficient Allocation: Water is allocated according to actual crop requirements and soil moisture levels, ensuring optimal use and balance.

BENEFITS TO SOIL HEALTH WITH RS AND GIS

1. Prevention of Erosion: GIS identifies erosion-risk zones; RS tracks land degradation for early conservation practices.
2. Nutrient Management: Remote sensing identifies nutrient deficiencies by vegetation index; GIS facilitates precise application of fertilizers where required.
3. Soil Health Monitoring: Integrated tools monitor the evolution of soil structure, salinity, and organic matter over time.

Crop Productivity Gains through RS and GIS

a. Improved Yields: RS enables monitoring crop growth and stress, allowing timely action to enhance output.
b. Quality Enhancement: GIS facilitates accurate input management to ensure maximum nutrient and water distribution for healthier crops.

Economic Gains through RS and GIS

1. Cost Savings: Targeted application of inputs avoids wasteful expenditure on water, fertilizers, and pesticides.

2. Resource Efficiency: Maximization of land, labor, and machinery utilization results in improved returns.
3. Increased Profitability: Enhanced yields and reduced input costs combined boost total farm revenue.

Implementation Challenges of Remote Sensing and GIS

Applications of Remote Sensing and GIS in agriculture have several challenges. The high capital investments and technical requirements restrict adoption, particularly among small farmers. Cloud cover compromises data quality and reliability. Combining datasets is a difficult task, and inadequate infrastructure in developing countries, i.e., limited power supply and internet, also restricts proper use of these technologies.

Trends in Agriculture in the Future

The future of irrigation and soil water management is changing very fast with the use of sophisticated digital technology. AI and Machine Learning will enhance decision-making and predictive modeling. IoT sensors will give real-time soil and weather information, while cloud computing will facilitate scalable data storage and processing. Drone technology will improve remote sensing and mapping abilities. Real-time analysis will make it possible to respond instantly to crop stress and irrigation requirements. Intelligent irrigation systems, integrating RS, GIS, and automation, will provide accurate water application.

These technologies have the promise to improve agriculture efficiency, sustainability, and resilience to climate adversity.

- Artificial Intelligence (AI): Facilitates smart decision-making and predictive analytics.
- Machine Learning: Enhances yield prediction and crop disease detection.
- IoT Sensors: Track real-time crop, weather, and soil data.
- Drone Technology: Applied to crop monitoring, spraying, and mapping.
- Smart Irrigation Systems: Provide water precisely as per need.
- Real-Time Analytics: Enables timely action to evolving field conditions.
- Robotics and Automation: Enhance efficiency in weeding, planting, and harvesting.
- Vertical and Urban Farming: Overcome land scarcity and provide year-round production.
- Sustainable Practices: Emphasize resource efficiency, biodiversity, and climate resilience.

Conclusion

The coupling of Remote Sensing and GIS has revolutionized soil water conservation and irrigation with data-based, site-specific, and efficient use of resources. With the increasing population pressures in India and globally, water shortages, and food security issues, the two technologies provide scalable solutions for sustainable agricultural growth. From the optimization of irrigation timing and soil moisture monitoring to watershed intervention planning and facilitating precision agriculture, RS and GIS facilitate decision-making and resource conservation over the long term. Even though obstacles remain in the form of high front-end expense and technical complexities, continuing innovation—be it AI, IoT, or drones—hopes to render these tools more affordable and effective. Adopting these innovations is crucial to realizing climate resilience, food safety, and sustainability within contemporary agriculture, while also enhancing productivity, conserving natural resources, and empowering farmers through informed, data-driven practices.

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Climate Change and Vegetable Production

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Remote Sensing (RS) and Geographic Information Systems (GIS) are increasingly becoming useful tools in managing irrigation water and conserving soil water. As water scarcity and food needs rise, these technologies assist in monitoring soil moisture, quantifying crop water use, water stress identification, and irrigation scheduling optimization. GIS allows watershed management, erosion control, and runoff simulation using spatial data analysis. Precision agriculture combines RS and GIS for variable rate application, yield estimation, and site management. The technologies enhance water use efficiency, minimize wastage, and increase crop yields. Although challenges such as high startup costs and technical complexity are there, emerging trends like AI, IoT sensors, drones, and real-time analytics hold out future solutions for sustainable, climate-resilient, and productive agricultural systems.

Introduction:

Vegetable crops are a critical component of the diet of humans, supplying essential vitamins, minerals, and fibre. Their production is extremely sensitive to climate conditions. Global warming, changes in precipitation, and increased frequency and severity of extreme events (floods, droughts, and storms) all directly affect vegetable production. Increased temperatures can reduce the duration of crops, impact flowering and fruiting phases, and change pest and disease ecology. Additionally, vegetable production is contributed hugely by smallholder farmers, who are disproportionately impacted, jeopardizing food security and livelihoods. This bulletin examines these

Vegetable crops are especially susceptible to the negative impacts of climate change. The compounded effects of increased temperatures, unpredictable rain patterns, accelerated pest and disease attacks, and frequent occurrences of extreme weather conditions are badly impacting crop yield, produce quality, and farmers' livelihoods. Without timely adaptation, these issues are likely to

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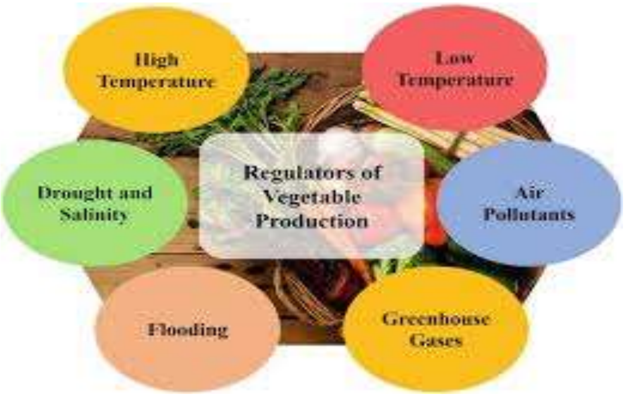
undermine vegetable production and food security at local, national, and international levels.



(Source, Bose and Pal, 2023)

Top Vegetable Production Impacts

Increased Temperatures

Increased average temperatures are causing heat stress in vegetable crops, which negatively impacts sensitive stages such as flowering and fruit setting. Lettuce, spinach, and cabbage crops are especially vulnerable, and excessive chilling temperatures tend to cause premature bolting, where plants start flowering too soon, severely lessening marketable yield and quality.

Water Stress

Irregular rainfall behavior and heightened frequency of droughts have interfered with conventional irrigation methods. Water stress retards seed germination, decreases soil moisture supply, and makes irrigation scheduling more difficult. These issues directly impact poor crop establishment and decreased yields.

Extreme Weather Events

The rising frequency of natural calamities like floods, hailstorms, and cyclones inflicts extensive physical damage to crop stands of vegetables. They bring about complete or virtually complete crop loss, taking severe financial distress to farmers along with supply chain losses.

Increased Pest & Disease Incidence

More favorable conditions in warmer climates for rapid reproduction and broader infestation of pests such as whiteflies, aphids, and a range of fungal diseases promote more frequent and intense pest and disease outbreaks. This raises the cost and intensity of crop protection.

Low Yield and Quality

The cumulative impacts of abiotic stresses, such as heat, drought, and flooding, lead to reduced fruit size, poor flavor, shorter shelf life, and increased chance of market rejection. Not only does this decrease farmers' income but also reduces the availability of healthy vegetables to consumers.

Adaptive Solutions for Climate-Resilient Vegetable Production

Climate-Resilient Varieties

The use of climate-resilient vegetable varieties is one of the major strategies for adapting to fluctuating environmental conditions. Farmers are urged to plant heat-tolerant, drought-tolerant, and disease-resistant hybrids or improved varieties that can maintain yields under stress. Such varieties are more capable of coping with increased temperatures, water scarcity, and emerging pest and disease problems resulting from climate change.

Effective Water Management

Effective water management is essential in maintaining vegetable production during times of erratic rainfall and drought. Methods like drip irrigation and sprinkler systems enable water delivery directly to plant roots, reducing wastage. Organic or plastic mulches assist in lessening soil evaporation, maintaining moisture, and preventing weeds. In addition, rainwater harvesting systems may be fitted onto farms to harvest and keep rainwater for use in times of drought, providing a more consistent supply of water.

Altered Dates of Planting

Adjusting planting dates is an effective means of mitigating the risk of crop loss from climate stress. By choosing sowing and transplanting times with care, farmers can ensure that the most vulnerable phases of vegetable development, including flowering and fruiting, are avoided in seasons of intense heat, excessive rain, or frost. Local agro-climatic information and weather forecasts can assist farmers in doing this.

Integrated Pest and Disease Management (IPDM)

Integrated Pest and Disease Management (IPDM) is a sustainable method of managing pests and diseases that are increasingly becoming more common with changing climate conditions. Regular field monitoring to identify initial signs of pest infestation, the encouragement of natural predators and biocontrol organisms, and pest-resistant varieties are part of this strategy. The careful and minimal application of chemical pesticides prevents the development of resistance while safeguarding useful organisms and the environment.

Protected Cultivation

Protected cultivation methods give a physical cover to vegetable crops from unfavorable weather. Low-cost structures like polyhouses, shade nets, and plastic tunnels are used to protect crops from intense heat, heavy rainfall, violent winds, and hailstorms. The structures give a more stable microclimate, allowing farmers to grow value-added vegetables throughout the year with improved yields and quality.

Soil Health and Organic Inputs

Soil health maintenance and improvement are central to climate-resilient vegetable production. Use of compost, farmyard manure, green manures, and biofertilizers improves soil water-holding capacity, structure, and nutrient status. These organic amendment practices reduce the reliance on inorganic fertilizers, enhance soil diversity, and ensure vegetable production systems are sustainable and climatic stress-resistant.

Conclusion

Climate change poses complex and growing challenges to vegetable production, affecting every stage from planting to harvest. The impacts on crop yield, quality, and farming livelihoods are significant and call for urgent action. However, by adopting adaptive strategies such as using resilient crop varieties, improving water use efficiency, adjusting planting dates, implementing integrated pest management, practising protected cultivation, and enhancing soil health farmers can reduce vulnerability and build more sustainable vegetable production systems. Collaborative efforts involving farmers, researchers, extension workers, and policy-makers are essential to ensure that vegetable farming remains productive, profitable, and capable of contributing to food and nutritional security in the face of climate change.

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Aquasilviculture: A Sustainable Approach to Integrated Coastal Resource Management

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Aquasilviculture is an integrated coastal resource management system that combines aquaculture with mangrove conservation or reforestation. This nature-based solution promotes environmental sustainability, economic viability, and social equity in coastal communities. In response to the harmful effects of conventional aquaculture, especially the large-scale clearing of mangroves, aquasilviculture offers a balanced approach that supports both ecological restoration and food production. This review explores the principles, benefits, challenges, pond construction methods, and future prospects of aquasilviculture as a sustainable livelihood strategy and an ecosystem-based adaptation tool.

Introduction:

Aquasilviculture is an ecologically sustainable farming practice that integrates aquaculture with the conservation and rehabilitation of mangrove forests. This approach was developed in response to the environmental degradation caused by intensive aquaculture, particularly the widespread clearing of mangroves. It aims to balance economic livelihood with ecosystem preservation. By cultivating aquatic species such as shrimp, fish, or crabs alongside the protection or replanting of mangrove trees, aquasilviculture provides dual benefits: supporting the economic needs of coastal communities while restoring essential coastal habitats. This method enhances biodiversity and water quality, and it strengthens natural defenses against coastal erosion and the impacts of climate change. As a nature-based solution, aquasilviculture is crucial for achieving long-term environmental sustainability and food security in coastal regions.

Principles of Aquasilviculture

Aquasilviculture is founded on the principle of harmonious coexistence between aquaculture and mangrove ecosystems, aiming for ecological balance, economic sustainability, and social equity. This

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approach typically allocates 60–70% of the farming area to mangrove conservation or reforestation, while the remaining 30–40% is designated for aquaculture ponds. This spatial arrangement facilitates natural tidal exchange and nutrient cycling, reducing the need for artificial inputs such as pumps or chemical treatments. By preserving mangrove cover, the system enhances biodiversity, improves water quality, and provides natural protection against coastal erosion and extreme weather events. Moreover, community participation, the use of native species, and eco-friendly farming practices are central to aquasilviculture, ensuring that both environmental and livelihood needs are met sustainably and inclusively.

Pond Construction and Layout

The construction and layout of ponds in aquasilviculture systems are meticulously planned to support aquaculture while conserving mangroves. Site selection focuses on low-lying coastal or estuarine areas that naturally experience tidal influences and have the potential for mangrove growth. Typically, the layout follows a 60:40 or 70:30 ratio, Ponds are constructed as shallow earthen basins, generally 0.8 to 1.5 meters deep, featuring well-compacted dikes and integrated water control structures, such as sluice gates, to manage tidal water exchange. Internal canals and buffer zones are included to ensure effective drainage and promote mangrove growth around the ponds. Mangrove trees are planted along pond embankments and in intertidal zones to stabilize the soil and enhance ecological functions. This integrated design fosters sustainable water management, minimizes environmental impact, and creates a balanced ecosystem that benefits both aquatic and terrestrial productivity.

Species Cultured and Mangrove Compatibility

Penaeus vannamei

Penaeus monodon

Aquasilviculture supports a variety of aquatic species that thrive in brackish water and coexist harmoniously with mangrove ecosystems. Commonly cultured species include shrimp (*Penaeus monodon* and *P. vannamei*), mud crabs (*Scylla serrata*), milkfish (*Chanos chanos*), and tilapia (*Oreochromis spp.*). These species can grow effectively in low-input systems that utilize natural food sources and experience minimal environmental stress, benefiting from the shelter, organic matter, and improved water quality provided by nearby mangroves.

Chanos chanos

Oreochromis spp.

Scylla serrata

Mangrove species such as *Rhizophora mucronata*, *Avicennia marina*, and *Sonneratia alba* are often integrated into aquasilviculture systems due to their robust root structures, high salinity tolerance, and ecological significance. Their presence not only stabilizes pond embankments but also enhances biodiversity and nutrient cycling. This synergy

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Avicennia marina

Rhizophora mucronata

Sonneratia alba

between aquatic and mangrove species ensures the resilience and productivity of the system, making aquasilviculture an ecologically sustainable and economically viable method of coastal aquafarming.

Benefits of Aquasilviculture

Aquasilviculture offers numerous environmental, economic, and social benefits, making it a sustainable alternative to traditional coastal aquaculture. Environmentally, it supports the restoration and conservation of mangrove forests, which act as natural water filters, carbon sinks, and protective barriers against storms and coastal erosion. By maintaining ecological balance, this system enhances biodiversity and improves water quality, reducing reliance on chemical inputs.

Economically, aquasilviculture provides diverse income opportunities for coastal communities through the cultivation of fish, shrimp, crabs, and mangrove-based products such as honey, fuelwood, and handicrafts. It also lowers operational costs by utilizing natural ecosystem services like tidal water exchange and organic waste recycling.

Socially, this approach empowers local communities by encouraging their active participation in resource management and conservation initiatives. It enhances food security, creates rural employment, and promotes knowledge sharing, all of which align with the broader goals of sustainable development and climate change adaptation.

Challenges and Limitations

Despite its sustainability benefits, aquasilviculture faces several challenges that impede its widespread adoption. One key limitation is its lower productivity compared to intensive aquaculture systems, as the emphasis on ecological balance restricts stocking density and feed input. Additionally, land tenure issues and policy conflicts can arise, particularly in areas where mangroves are protected or ownership rights are ambiguous, creating barriers to long-term investment and management. Farmers may lack the technical knowledge and training needed to effectively manage integrated systems, especially regarding water quality, species compatibility, and mangrove maintenance. Furthermore, the initial costs and labor required for mangrove planting and infrastructure development may deter smallholders. Regular monitoring and enforcement of sustainable practices are also challenging in community-based settings without adequate support. Addressing these limitations requires strong institutional support, community engagement, access to technical guidance, and policies that promote conservation-oriented aquaculture practices.

Global and Regional Applications

Aquasilviculture has been successfully implemented in various countries, particularly in tropical and subtropical coastal regions where mangroves and aquaculture coexist. In the Philippines, the National Aquasilviculture Program (NAP) has been instrumental in integrating fish and shrimp farming with mangrove reforestation, involving coastal communities in both livelihood development and environmental rehabilitation. Similarly, Vietnam and Indonesia have adopted silvofisheries models within their mangrove-shrimp farming systems, aided by government policies and support from international organizations to combat mangrove loss and promote sustainable aquaculture. In Bangladesh, integrated mangrove-aquaculture practices have demonstrated potential in enhancing resilience to climate change and improving rural incomes. These regional initiatives illustrate the adaptability of aquasilviculture across different ecological and socio-economic contexts, providing valuable lessons for scaling up the approach globally. Through community participation, institutional support, and knowledge sharing, aquasilviculture is increasingly recognized as a viable solution for sustainable coastal resource management.

Future Prospects

The future of aquasilviculture looks promising as the world increasingly embraces nature-based solutions to address climate change, biodiversity loss, and food security. With growing awareness of the ecological and economic benefits of mangroves, aquasilviculture offers a scalable approach to sustainable coastal development. Innovations in low-impact aquaculture practices, enhanced mangrove restoration techniques, and digital monitoring tools can improve the efficiency and appeal of these systems. Furthermore, the rising demand for eco-certified seafood and blue carbon credits creates new economic incentives for communities and investors to adopt integrated approaches. Policymakers are also recognizing the importance of aquasilviculture in national climate adaptation and coastal protection strategies. By fostering community engagement, providing technical support, and integrating effective policies, aquasilviculture has the potential to transform degraded coastlines into productive, resilient ecosystems that support livelihoods and long-term environmental health.

Conclusion

Aquasilviculture is a sustainable and holistic approach to coastal resource management that combines aquaculture with mangrove conservation. It addresses the urgent need to balance environmental preservation with economic development, offering a viable solution to the ecological degradation caused by intensive aquaculture practices. By prioritizing biodiversity, natural water management, and community involvement, aquasilviculture enhances the resilience of coastal ecosystems while supporting local livelihoods. Although it faces challenges such as lower yields and technical limitations, the long-term environmental, social, and economic benefits make it an appealing model for sustainable development. With increased support from governments, researchers, and international agencies, aquasilviculture has the potential to become a cornerstone of climate-resilient coastal farming and a blueprint for integrated natural resource management worldwide.

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Novel Ways to Use Water for "Per Drop More Crop"

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Water scarcity presents a challenge of utmost concern for agriculture, and there is a need for smarter, more effective use of every drop. The "Per Drop More Crop" approach encourages new practices such as precision irrigation, drought-tolerant crop selection, rainwater harvesting, and digital technologies to enhance water-use efficiency. Community-based initiatives, government support programs, and farmer training also support adoption. These practices not only save water but also enhance crop productivity, soil health, and farmer revenues. This bulletin discusses innovative, pragmatic approaches to enabling farmers to produce more with less in order to ensure sustainable agriculture and water security in a time of climate uncertainty.

Introduction:

Headline: "Every Drop Counts – The Future of Farming Depends on It"

Water is the cornerstone of agriculture, but it is one of the most underappreciated and overused resources in agricultural systems. Agriculture globally consumes over 70% of all freshwater withdrawals. In India, this percentage is even greater, subjecting the already scarce water resources to enormous pressure. As population, urbanization, and industrial requirements grow, freshwater resources available to agriculture are becoming smaller and smaller. Added to this are uncertainties of rainfall, climatic change, and inefficient irrigation systems that result in excessive water losses as well as low productivity. Kumar *et.al.* 2021.

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Smallholders and farmers are most impacted by water scarcity. Aquifer depletion and uneven weather patterns decrease the reliability of conventional farming practices. In much of the world, water scarcity has already started to affect crop yields, agricultural prices, and rural incomes. If action is not taken, this crisis can jeopardize long-term food and water security.

The solution lies in making each drop of water count. "More Crop Per Drop" is the principle that calls for improving water-use efficiency without sacrificing productivity. With the use of improved irrigation practices, better soil management, the use of climate-resilient crops, and rainwater harvesting, farmers can cut their water footprint considerably without sacrificing yields or even increasing them.

The vision is cogent: intelligent water use not only increases farm production but also facilitates environmental sustainability and economic viability for farmers. Effective water management saves on input costs, improves soil fertility, and maintains groundwater resources for posterity.

This bulletin presents new and effective methods for conserving water in agriculture. From technological measures to indigenous knowledge, the aim is to equip farmers with the information and tools necessary to survive under water scarcity. Through collaborative effort and careful planning, we can make agriculture productive, profitable, and sustainable – drop by invaluable drop.

Source: https://www.ksgindia.com

3.Precision Irrigation Techniques

Headline: "Target the Roots, Not the Floods"

Flood irrigation has been practiced in agriculture for centuries, but it is also one of the least efficient methods of watering crops. Much of the water is lost through evaporation, runoff, and deep percolation. With increasing water scarcity and uncertain rainfall, there is an imperative to move towards precision irrigation technologies that deliver water in an efficient manner—where it is needed: the root zone of the plant. Malhotra *et.al.*2016.

Drip irrigation is the most efficient system to save water. It provides water straight to the root of every plant via an array of tubes, emitters, and valves. Not only does this save water, but it also limits weed growth and enhances fertilizer effectiveness. Farmers employing drip systems indicated saving 40–60% of water used with improved yields.

Sprinkler irrigation is another water-saving method, particularly effective for small to medium fields. It imitates rainfall by spraying water over the field, providing uniform coverage and saving labor. New sprinklers are easily transported and adjusted according to different crops.

Smart irrigation controllers go a step further in terms of efficiency by leveraging information from soil moisture sensors, weather forecasts, and the growth stages of crops to automate the watering process. They ensure that plants are given the appropriate amount of water at the appropriate time to avoid both under- and over-irrigation.

Subsurface irrigation is the process of placing pipes under the ground, irrigating directly into the root zone. It is extremely efficient, particularly in dry areas, as it practically eliminates evaporation from the surface and wind drift.

Tip: Mulching-organic or plastic-around plants retains moisture in the soil, minimizes evaporation, and smothers weeds, which further adds value to precision irrigation systems.

4. Crop Selection and Water-Wise Strategies

Headline: "Grow Smart, Save Water"

Selecting the appropriate crops and implementing water-wise farming practices are important measures toward "More Crop Per Drop." Water efficiency is not dependent solely on irrigation but begins with what and how we plant. Drought-tolerant crops like millets, pulses, and oilseeds are inherently suited to arid climatic conditions and need much less water

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than other water-needy crops like sugarcane and paddy. Millets, for example, have a good growth in semi-arid areas, mature early, and are also nutritious, providing both environmental as well as economic advantages. Shroff *et.al.* 2024.

Crop rotation is an age-old technique that changes different crops in the same field seasonally. It not only enhances soil fertility but also cuts down on pest and disease buildup, resulting in healthier crops with lower water and chemical use requirements. Legumes, if rotated with cereals, can even fix nitrogen in the soil, which further increases productivity at reduced water requirements. Direct seeding, particularly in rice production, obviates the use of water-scarce nurseries and transplanting. Sowing seeds directly into the field allows the farmer to conserve both labor and water while shortening the growing period. Agroforestry, or the combination of trees with crops or livestock, has several advantages. Trees conserve soil moisture by slowing down wind speed and shading the ground, hence decreasing evaporation. The roots of trees also enhance water infiltration and soil structure, thus making the land more resistant to drought.

Case Study: A Gujarati farmer introduced pearl millet farming along with drip irrigation. The outcome? 40% more yield and 50% less water consumption, highlighting the potential of crop selection and efficient irrigation to revolutionize productivity.

By coordinating crop selection with the local climate and embracing sustainable methods, farmers can assure their harvests—and their water supplies—for generations to come.

5. Water Harvesting and Recharge

Headline: "Store It When It Rains, Use It When It Drains"

Rainwater is a valuable natural resource—yet in many agricultural areas, a vast majority of it is wasted as surface runoff. By collecting and storing rainwater during the monsoon, farmers can secure irrigation water supplies during dry spells. By harvesting water, not only is there availability throughout the year, but there is also less reliance on over-exploited groundwater resources.

Farm ponds and check dams are easy but very effective structures. Farm ponds provide a space for rainwater to collect in lowlands and can be utilized for irrigation, aquaculture, or animal rearing. Check dams, built across small gullies or streams, retard the movement of water and recharge groundwater while avoiding erosion.

Roof rainwater harvesting is especially suitable for greenhouses, storage sheds, or shelters for livestock in farms. Water harvested from roofs can be placed in tanks and utilized for nurseries, tool washing, or animal watering. The approach is cheap and hassle-free.

Percolation tanks and recharging wells also serve an important function to recharge groundwater. Percolation tanks are shallow, wide facilities through which water slowly percolates into the ground and recharges aquifers. Recharge wells, usually excavated close to borewells or open wells, help ensure rainwater excess directly seeps into underground water sources.

Contour bunding, particularly in sloping or hilly ground, retains water through minimizing runoff. Bunds catch rainwater following the contours of the ground, raising the availability of moisture and reducing soil erosion. They also enhance the efficiency of irrigation over time.

Stat: Studies indicate that efficient water harvesting can lower the demand for irrigation by 25–50% per year, with both economic and environmental advantages.

6.Technology and Data in Water Management

Headline: "Farming Meets Innovation"

Today's agriculture is not merely soil and seeds anymore—it's also sensors, satellites, and software. Technology is revolutionizing how water is handled on farms, enabling farmers to make data-driven decisions that save time and money, and most importantly, save water.

Soil moisture sensors revolutionize irrigation. Installed in the field at root level, these sensors

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monitor the amount of water in the soil in real time. It avoids over-irrigation and delivers precisely what the crops require, not one drop more, not one drop less. The outcome is healthier crops and enormous water savings.

Remote sensing and GIS enable farmers and agricultural planners to check huge patches of land for crop well-being, drought, and water efficiency through satellite photography and UAVs (drones). These technologies give precise information regarding where intervention is required, enabling water resources to be directed more efficiently.

Mobile applications and digital dashboards place sophisticated tools in farmers' hands. Using only a smartphone, they can get localized weather reports, soil information, and irrigation advice. Applications such as e-Krishi, mKisan, and state-level platforms provide real-time information and tips matched to regional needs and languages.

IoT-connected pumps and intelligent valves take it a notch higher by making the irrigation process automated. The equipment can be scheduled to work at the best times and flow rates depending on the needs of the crop and weather. It minimizes labor while optimizing water usage efficiency.

Toolbox Highlight: Services such as e-Krishi, mKisan, and Kisan Suvidha provide a range of services—market prices, weather forecasts, irrigation advice, and expert opinions—encouraging farmers to move towards better practices.

7. Policy Support and Community Action

Headline: "Water Wisdom Starts with Us"

Though technology and methods are crucial in water-efficient agriculture, actual and enduring change occurs when communities organize and policy frameworks enable sustainable action. Water management isn't merely a farm-level issue—it is one that relies on collective action, government assistance, and community leadership.

Watershed development schemes are one of the strongest tools for water conservation at the local level. Such schemes consist of constructing small structures such as check dams, contour bunds, and recharge pits over a watershed land to trap rainwater, decrease runoff, and recharge groundwater. Carried out under local initiative, these schemes contribute towards augmenting both availability of water and agricultural yields in the long run. Tyagi, *et.al.* 2019.

Subsidies for micro-irrigation, particularly under schemes such as the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), are promoting the use of drip and sprinkler systems among farmers. Subsidies greatly lower the initial cost of installation, bringing efficient irrigation within reach even of small and marginal farmers.

Water User Associations (WUAs) give farmers the power to manage and allocate water resources together. Through such formations, communities can establish equitable schedules of water use, avoid over-extraction, and maintain common facilities. WUAs promote a sense of belonging and responsibility, hence sustainable water management.

Farmer training and awareness programs have a strong impact on mindset shifts. Field demonstrations, workshops, and knowledge-sharing programs enable farmers to learn about the long-term advantages of water-saving measures and how to adopt these. Farmers are more likely to adopt these if they can see successful instances in their own neighborhood.

Ultimately, water wisdom begins with us—with all farmers, all villages, and all policymakers taking collective action. By leveraging the power of modern policy support, linked with local action, we can create a future where water is wisely used, agriculture is resilient, and rural livelihoods thrive.

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Biochar: A Sustainable Solution for Soil Health and Climate Resilience

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Biochar, a carbon-rich material derived through the pyrolysis of biomass in an oxygen-limited environment, has emerged as a versatile and eco-friendly tool in agriculture and environmental management. Its application spans centuries, with historical examples like the Amazon's terra preta soils illustrating its agronomic benefits. biochar is known for its ability to enhance soil fertility, structure, and water retention, particularly in arid and nutrient-poor regions. Its porous architecture aids in nutrient retention, promotes microbial activity, and even adjusts soil pH, fostering healthier ecosystems. Beyond its use in agriculture, biochar helps mitigate climate change by reducing greenhouse gas emissions such as nitrous oxide and methane and sequestering carbon over an extended period of time. In addition to helping with soil and water restoration, its capacity to absorb toxins offers answers to environmental problems. By maximizing nutrient availability and water use, as well as improving insect control and soil health, biochar increases agricultural yield and sustainability in everything from rice paddies to vegetable farms. Its potential is still being unlocked by continuous research and development, despite obstacles like production cost and quality unpredictability. Essentially, biochar is a key component of sustainable agricultural systems, combining practical uses in a variety of farming scenarios with ecological advantages. It is a potential frontier for global food security and environmental stewardship because its incorporation into contemporary agriculture not only increases yields but also fortifies efforts to fight climate change.

Introduction:

Biochar represents a carbon-dense material synthesized through the pyrolysis process, wherein organic matter—comprising plant residues, timber, or agricultural byproducts—is subjected to elevated temperatures in an anoxic environment. The outcome is a stable, charcoal-like entity that offers a multitude of ecological and agronomic advantages.

Primarily, biochar functions as a soil amendment aimed at enhancing soil fertility, hydric retention, and nutrient bioavailability. Its inherently porous

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architecture facilitates the retention of water and nutrients, rendering it especially advantageous for arid and nutrient-deficient soils. Furthermore, biochar possesses the capacity to mitigate greenhouse gas emissions from soils and to sequester carbon over extended durations, thereby contributing to efforts aimed at climate change mitigation.

Historically, biochar has been utilized in agricultural practices for centuries, with prominent instances such as the "terra preta" soils of the Amazon basin, which were augmented with biochar to improve their fertility. Contemporary research persistently investigates its potential applications in domains such as water purification, waste management, and the production of renewable energy.

Soil Health Improvement:

Enhanced soil structure: Biochar contributes to the amelioration of the soil's physical characteristics, rendering it more porous and optimizing water retention, which is particularly advantageous in sandy soil compositions.

Augmented nutrient retention: Biochar possesses the capacity to adsorb essential nutrients such as nitrogen, phosphorus, and potassium, thereby mitigating their leaching from the soil. This phenomenon leads to more effective fertilizer utilization and diminishes nutrient loss.

Elevated soil pH: In the context of acidic soils, biochar can function as a liming agent, facilitating an increase in soil pH and diminishing acidity, thus rendering the soil more conducive to plant growth.

Water retention: The porous architecture of biochar significantly enhances its water-retaining capabilities, rendering it beneficial for agricultural methodologies in arid and drought-affected regions. It can diminish the necessity for irrigation by optimizing moisture availability within the root zone.

Enhanced microbial activity: Biochar furnishes a conducive habitat for beneficial soil microorganisms, thereby amplifying microbial activity and diversity. This enhancement fosters nutrient cycling, organic matter decomposition, and the overall health of the soil ecosystem.

Carbon sequestration: Biochar exhibits a remarkable degree of stability, with the potential to persist in the soil for centuries to millennia, sequestering carbon and alleviating climate change by curtailing the emission of carbon dioxide (CO_2) into the atmosphere.

Application Methods in Agriculture:

Soil amendment: The incorporation of biochar into soil, whether utilized independently or in conjunction with compost or fertilizers, is a prevalent practice. Its application is widespread across horticultural endeavors, agricultural field crops, and forest management practices.

Compost additive: The integration of biochar into compost serves to augment the composting process by fostering microbial activity and mitigating greenhouse gas emissions during the decomposition phase.

Crop-specific application: The response of various crops to biochar application can differ considerably. For example, legumes and vegetables may derive substantial benefits from the application of biochar, particularly in soils that are deficient in essential nutrients.

Interaction with fertilizers: Biochar exhibits a synergistic relationship with fertilizers, enhancing their efficiency by minimizing nutrient leaching and facilitating a gradual release of nutrients over time, thereby decreasing reliance on chemical inputs. Its efficacy is notably amplified when used in conjunction with organic fertilizers, such as manure or compost.

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Environmental benefits: Reduced Greenhouse Gas Emissions: By sequestering carbon in a stable form, biochar contributes to the reduction of CO2 emissions. Furthermore, it has the capacity to diminish methane and nitrous oxide emissions emanating from soil systems.

Pollution mitigation: Biochar possesses the ability to adsorb heavy metals and organic contaminants, thereby assisting in the remediation of polluted soils and enhancing the quality of water in agricultural runoff.

Challenges and Considerations:

Biochar quality: The efficacy of biochar is contingent upon the feedstock employed and the specific conditions under which it is produced. Variations in biochar properties necessitate a comprehensive understanding of the particular requirements of both soil and crops.

Cost: The production and transport of biochar can incur significant expenses, although advancements in technology and broader adoption may lead to a reduction in these costs.

Long-term effects: While the short-term advantages of biochar are well-documented, research is ongoing to ascertain its long-term impacts on soil health and agricultural productivity.

Sustainability and climate change mitigation: The utilization of biochar is congruent with sustainable agricultural methodologies, as it enhances soil health, diminishes the necessity for synthetic inputs, and contributes to climate change mitigation efforts through carbon sequestration. Furthermore, biochar can be incorporated into circular farming systems, utilizing waste materials such as crop residues or manure as feedstocks.

Applications in different agricultural systems: Small-scale Farming: Within subsistence farming or smallholder agricultural systems, biochar can be produced locally from available biomass and employed to enhance soil fertility.

Large-scale Agriculture: In a commercial context, biochar can be utilized to improve soil characteristics and enhance agricultural yields, particularly in soils that are degraded or lacking in nutrients.

Usage of Biochar in the Field:

Rice Production: Under paddy cultivation, the incorporation of biochar possesses the capacity to alleviate methane emissions while concurrently enhancing rice productivity through the optimization of soil aeration and the availability of essential nutrients. Biochar, a carbon-dense substance produced via the pyrolysis of biomass, has demonstrated significant potential in the field of rice agriculture.

Soil Fertility Improvement: Biochar serves to augment soil nutrient availability, particularly with respect to nitrogen, phosphorus, and potassium—elements that are indispensable for the growth and development of rice.

Carbon Sequestration: The application of biochar fosters carbon sequestration, thereby contributing to the reduction of greenhouse gas emissions and the enhancement of soil organic matter.

Methane Emission Reduction: The strategic application of biochar in paddy fields markedly diminishes methane emissions, thereby lessening the ecological repercussions associated with rice farming.

Crop Productivity: Empirical studies suggest that the utilization of biochar can elevate rice yield and facilitate seedling development, contingent upon the specific dosage and genetic variation of the rice cultivar.

Economic Feasibility: The implementation of biochar can be deemed economically viable under particular circumstances, presenting a sustainable methodology for rice agricultural practices.

Vegetable Farming: Biochar is extensively utilized within the realm of vegetable cultivation to strengthen soil fertility and improve moisture retention, culminating in enhanced yields and more robust plant growth. Various advantages for scholarly investigation include:

Soil Health: Biochar contributes to the enhancement of soil structure, water retention, and nutrient accessibility, all of which are pivotal for the growth of vegetables.

Pest Control: Its application can mitigate pest infestations by fostering beneficial soil microbiota and establishing conditions that are inhospitable to certain pest species.

Carbon Sequestration: The incorporation of biochar into vegetable farming practices aids in carbon sequestration, thereby promoting sustainability within the agricultural sector.

Yield Improvement: Research indicates that biochar has the potential to augment vegetable yield and enhance the overall quality of the crops produced.

Environmental Benefits: The use of biochar assists in the reduction of greenhouse gas emissions and the effective management of agricultural waste**.**

Conclusion:

Biochar presents considerable potential for the enhancement of soil fertility, the improvement of water retention, and the reduction of greenhouse gas emissions. Although further research is necessary to fully elucidate its long-term advantages, it is increasingly regarded as a sustainable and effective instrument in agriculture, particularly in the face of challenges related to climate change and soil degradation. The judicious application of biochar can foster more resilient agricultural systems, especially in regions subjected to environmental stressors.

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Urban Forestry: A Solution to Environmental and Public Health Challenges

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Urban forestry the organized planning, management, and development of trees and open spaces in urban environments has become more important in the fight against the complex, interdependent environmental and public health challenges arising from rapid urbanization. Urban areas, especially in developing countries, are facing increasing air pollution, heatwaves, reduced biodiversity, and an increase in non-communicable diseases associated with physical inactivity and stress. Urban forests function as a natural infrastructure that provides an array of ecosystem services: they mitigate urban microclimates by moderating the urban heat island effect, cleanse pollutants to enhance air and water quality, and sequester carbon and help mitigate climate change.

Apart from environmental advantages, urban green spaces significantly contribute to improved public health by promoting physical activity, stress reduction, better mental well-being, and increased social cohesion through common community areas. Urban forestry also enhances resilience against climate change by lowering stormwater runoff, preventing erosion, and maintaining urban wildlife habitats. This article analyzes the potential of urban forestry as a comprehensive and sustainable strategy to make cities healthier, more livable places while stressing the necessity of integrated policies, public engagement, and long-term planning to achieve its maximum benefits.

Cities are now home to more than half the world's population, a number that is set to increase dramatically in the next few decades. With this fast-paced urbanization comes a number of environmental and public health issues. Compact concrete infrastructure, declining green cover, rising vehicular and industrial emissions, and the rise in frequency of extreme weather events have resulted in declining air and water quality, rising urban heat island effects, and a rise in lifestyle diseases like obesity, anxiety, and respiratory disorders. There is an increasing disconnection between urban residents and nature, undermining ecological resilience as well as human health.

On this front, urban forestry is a promising, sustainable, and nature-based solution. Urban forestry encompasses the systematic planning, planting, protection, and management of trees and related vegetation within and around towns and cities. Apart from enhancing environmental quality, urban forestry also beautifies the urban landscape, offers recreational facilities, and supports physical and mental well-being. By incorporating trees into the city fabric—along streets, in parks, around buildings, and along waterways—urban forestry provides a way to harmonize ecological integrity with city growth. Urban forestry is a foundation of resilient, livable, and sustainable cities.

2. What is Urban Forestry?

Urban forestry is the planned planting, maintenance, management of trees and linked vegetation in urban areas. Urban forestry covers a broad array of green spaces including public parks, street plantings, institutional campuses, residential gardens, and even industrial settings. As opposed to traditional forestry, which is basically timber production and rural ecosystem-oriented, urban forestry aims at city resilience and human welfare. It not only has an important role to play in beautification, but also as a strategic measure to check urban environmental degradation, improve public health, and ensure community well-being. With properly planned urban forestry programs, cities can be made more livable, sustainable, and climate-resilient.

3. Environmental Benefits of Urban Forestry

Urban forests provide a variety of environmental services directly responding to the ecological issues in contemporary cities. These advantages are imperative for enhancing urban living and constructing long-term climate change resilience.

3.1. Air Quality Improvement

Urban trees serve as natural air filters. Their leaves adsorb gaseous pollutants like sulfur dioxide (SO_2), nitrogen oxides (NO_x), and ozone (O_3), and trap particulate matter (PM2.5 and PM10) on their surface. This filtering action improves the quality of urban air, particularly in densely trafficked and industrially active areas. Urban forests decrease the level of airborne pollutants, thus lowering respiratory diseases and enhancing public health improvements.

3.2. Mitigation of Urban Heat Island

Perhaps the most urgent environmental issue in cities is the urban heat island (UHI) phenomenon, in which urban areas tend to be substantially warmer than surrounding rural areas. Trees naturally cool by shading and evapotranspiration, through which water is evaporated from leaves into the air. Strategically located trees have the potential to reduce local temperatures by 2-8°C, hence decreasing the severity of heat waves, decreasing air conditioning energy demand, and increasing outdoor spaces' comfort and safety for residents.

3.3. Carbon Sequestration

Urban forests are of pivotal importance in mitigating climate change as they act as carbon sinks. Trees remove carbon dioxide (CO_2) from the atmosphere through photosynthesis and lock it within their biomass. While the net carbon sequestration capacity of urban trees is limited compared to vast natural forests, the fact that they are based near sources of pollution such as automobiles and industries means that their relative contribution to greenhouse gas emission mitigation in cities is significant.

3.4. Stormwater Management

Rainfall is intercepted by tree canopies, hence decreasing the volume and velocity of surface runoff, subsequently reducing urban flooding and sewer overflows. Tree roots further enhance soil structure and permeability, leading to groundwater recharge and soil erosion prevention as well as waterlogging. On cities where impervious surfaces are prevalent, urban forests serve as critical elements of green infrastructure for sustainable water management.

3.5. Biodiversity Support

Urban green spaces are essential to preserving biodiversity in urban environments. They offer habitats and sources of food for diverse wildlife within the urban area, such as birds, pollinators, insects, and small mammals. In addition, they act as ecological corridors, allowing fragmented habitats to be linked and facilitating species movement. Urban forestry therefore plays a role in preserving urban biodiversity, adding value to the urban ecosystem, and facilitating pollination and pest control services.

4. Public Health Value of Urban Forestry

Urban forestry not only enhances the ecological quality of cities but also provides significant public health dividends. Trees and green areas add up to physical, mental, and social well-being, and make cities healthier and more equitable.

4.1. Physical Health Enhancement

Urban trees benefit physical health by providing comfortable, shaded conditions that invite outdoor recreation like walking, jogging, and cycling. By offering protection from heat and sunlight, tree-lined walkways and parks facilitate easy access of individuals of all age groups to regular exercise. Further, urban greenery lowers the level of air pollutants, consequently reducing the prevalence of respiratory ailments, cardiovascular illnesses, and heat stress, particularly among children, the aged, and susceptible groups.

4.2. Mental Health and Reduction of Stress

Natural exposure to green spaces has a long documented effect of stress relief on mental well-being. Exposure to parkland and wooded areas has been associated with lower rates of depression, anxiety, and stress. Green environments provide a restorative setting that enhances mood, concentration, and emotional resilience. Even passive exposure, including looking out at trees from a window or walking through a garden, improves cognitive function and diminishes mental exhaustion in city residents.

4.3. Social Cohesion and Equity

Urban green spaces are also social gathering centers that promote community engagement, cultural activities, and recreation. Urban green spaces contribute to social cohesion by creating inclusivity, safety, and a sense of belonging. Notably, when the urban forests are equitably spread throughout all neighborhoods, they contribute to minimizing health inequalities by ensuring equal access to the health gains of nature. In poor or marginalized communities, this can have a redemptive effect, advancing environmental justice and well-being.

4.4. Noise Reduction

Under dense urban conditions where traffic and construction generate high levels of noise, trees and green cover function as effective natural barriers against noises. Their leaf cover and physical structure absorb, reflect, and diffract the sound waves, thus lessening ambient noise pollution. This, apart from enhancing comfort levels in living and institutional zones, also leads to improved sleep and less stress for city residents.

5. Economic Benefits

Urban forestry not only has ecological and health benefits but also real economic rewards for individuals and cities. Perhaps the most widely known impact is the rise in property values; houses and business places near green areas and tree-lined avenues usually fetch a higher market value because of enhanced beauty and environmental conditions. In addition, the shade from urban trees cuts down on summer artificial cooling needs, resulting in substantial energy savings and reduced household electricity charges. On an overall economic level, urban forestry initiatives create employment opportunities across different sectors including tree planting, pruning, landscape design, nursery business, and green infrastructure maintenance. These operations support the local economy and create a green employment culture.

6. Challenges to Urban Forestry

While advantageous, the application and viability of urban forestry programs have several challenges. One of them is a lack of land availability in highly populated cities where real estate use frequently surpasses green space utilization. Urbanization and infrastructure development further restrict efforts for mass planting of trees. Besides that, inefficient planning and maintenance strategies, such as the application of non-native species or a lack of post-planting care, contribute to low survival rates and fewer ecosystem services. Urban trees also experience climate stresses, such as drought, air pollution, and heat waves, which weaken their health and lifespan. Additionally, green spaces without proper protection are at risk of vandalism, unauthorized encroachment, and deterioration, reducing community access and ecosystem integrity.

7. Strengthening Urban Forestry Strategies

To address these challenges and unlock urban forestry's full potential, an integrated set of strategies is needed. The integration of green infrastructure in urban planning documents like city master plans and zoning regulations ensures trees are considered essential urban assets. Community engagement is central; involving local residents, schools, non-governmental organizations, and corporate volunteers in tree care and planting encourages stewardship and collective responsibility. Choosing the right tree species is critical; cities must use native, drought-resistant, and pollution-resistant trees to enhance survival and resilience. Government incentives and policies can further encourage urban greening by subsidizing rooftop gardens, green belts, and vertical landscaping, or offering tax relief or mandating them. Finally, the integration of technologies such as GIS, remote sensing, and IoT-based monitoring systems can assist in real-time evaluation of urban green cover, provide direction to maintenance operations, and aid data-driven policymaking.

9. Conclusion

Urban forestry is a revolutionary strategy for the connected dilemmas of environmental degradation and public health in the fast-growing urban regions. By incorporating trees and green infrastructure into cities, urban forestry not only improves the ecological balance but also helps to significantly enhance air quality, mitigate urban heat, handle stormwater, and promote mental and physical wellness. It makes urban areas more livable, resilient, and inclusive. But the success of urban forestry hinges on holistic and coordinated strategies with urban planners, policymakers, environmental scientists, community residents, and private stakeholders. Strategic planning, scientific plant selection, persistent upkeep, and public participation are key pillars to guarantee long-term success. Investing in urban forestry is thus an investment in the future well-being, sustainability, and vitality of our cities.

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Agroforestry in West Bengal: Balancing Agricultural Productivity and Environmental Sustainability: A Review

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Agroforestry in West Bengal combines trees with crops and livestock, thereby improving agricultural productivity and promoting environmental sustainability. This article explores its significance in sustainable land use, as well as its impact on farm and soil health across various climatic regions, alongside current practices. Despite its historical importance, there are rising concerns regarding long-term sustainability and economic viability. The state is confronted with challenges such as land degradation and climate change, which pose threats to ecological stability and economic resilience. This review emphasizes the contributions of agroforestry to soil health, biodiversity, and community welfare, while also addressing the challenges of implementation and providing policy recommendations for sustainable development in West Bengal.

Introduction

Agroforestry in West Bengal represents a transformative land-use strategy that confronts the intertwined challenges of agricultural productivity and environmental sustainability. By incorporating trees, crops, and livestock, it improves soil fertility, enhances productivity, and promotes biodiversity while addressing concerns such as soil degradation, climate change, and diminishing farm incomes. This method is particularly well-suited to the state's varied agro-climatic zones, providing both flexibility and adaptability. In addition to boosting productivity, agroforestry plays a significant role in carbon sequestration, nutrient cycling, and microclimate regulation, while also fostering rural development by increasing farmers' incomes and supplying resources for biofuels. Effective implementation necessitates a supportive framework that includes clear land rights, strong policies, scientific advancements, and training for farmers. The National Agroforestry Policy (2014)

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further underscores the importance of integrating trees into farming systems to create a resilient agricultural ecosystem. Adopting agroforestry can reconcile economic viability with environmental stewardship, ensuring long-term sustainability, food security, and enhanced livelihoods for rural communities, while also revitalizing degraded landscapes and empowering farmers to tackle contemporary challenges.

The Importance of Agroforestry

Agroforestry plays a crucial role in meeting the rising demands for food and resources, its historical importance in sustaining rural communities, and the environmental advantages it offers, such as moderating microclimates and sequestering carbon. This practice fosters positive interactions between plants and animals, thereby increasing productivity, maintaining soil health, and bolstering resilience in agricultural systems while alleviating the strain on natural resources

Agroforestry Models in West Bengal

West Bengal presents a diverse range of agroforestry practices influenced by its physiographic regions and agricultural systems. Notable agroforestry systems include agri-silviculture, silvo-pastoral systems, agro-silvo-culture, windbreaks, forest farming, home gardens, taungya farming, and agri-horti-silviculture. These methods combine trees with crops and livestock, thereby enhancing productivity, biodiversity, and resilience. They offer numerous advantages, such as improved soil health, income diversification, and ecosystem services, while also promoting sustainable land use and food security. By maximizing land use and encouraging beneficial interactions, agroforestry systems play a crucial role in supporting rural livelihoods and environmental sustainability, making them essential for tackling contemporary agricultural challenges.

Agricultural Productivity Advantages

Agroforestry boosts agricultural productivity by creating beneficial interactions between trees and crops, enhancing soil health, and fostering biodiversity. It increases soil nutrients through the action of nitrogen-fixing trees and the breakdown of organic matter, while also conserving soil and water by minimizing erosion and improving water retention. Furthermore, agroforestry enhances microclimatic conditions, which supports crop stability and growth. This approach offers various revenue sources, providing farmers with additional income from fruits, nuts, and timber, thus reducing risks linked to poor harvests and market volatility. In summary, agroforestry offers a sustainable alternative to monoculture farming, promoting long-term agricultural sustainability and resilience.

Key financial opportunities in agroforestry include

Agroforestry presents various financial opportunities: multi-crop farming guarantees consistent income, the integration of livestock boosts productivity, sustainable timber production yields long-term profits, and agro-tourism leverages the demand for organic products. Furthermore, investing in traditional systems fosters food security and enhances the livelihoods of farmers by tackling environmental issues and improving access to nutrition.

Positive Impacts of Environmental Sustainability

Agroforestry provides considerable environmental advantages, such as carbon sequestration, the preservation of biodiversity, control of soil erosion, and a decrease in chemical reliance. It improves carbon capture through a variety of plant systems, bolsters ecosystem stability by creating habitats for numerous species, and addresses soil erosion with effective canopy cover and root structures. Furthermore, agroforestry minimizes pesticide drift by as much as 90% through the use of windbreaks and hedgerows, safeguarding beneficial insects and encouraging integrated pest management. These methods not only alleviate climate change and improve soil health but also enhance sustainable agricultural productivity and resilience, establishing agroforestry as a comprehensive strategy for environmental sustainability.

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Challenges to Agroforestry Adoption

Agroforestry in West Bengal is confronted with challenges like lower profitability relative to monoculture, a decrease in agricultural productivity due to the introduction of trees, and insufficient knowledge among farmers about practices and species selection. Additionally, it may negatively influence food production and crop yields through shading and competition for resources, making pest management more complex.

Policy Recommendations and Initiatives

West Bengal intends to advance agroforestry by providing operational support, fostering public-private partnerships, and establishing pre-production agreements to ensure price stability. The initiatives encompass the integration of agroforestry into crop insurance, conducting research, increasing public awareness, and certifying sustainably produced goods to improve market acceptance and foreign exchange earnings, with the goal of achieving national agroforestry objectives.

Advancing agroforestry through the creation of suitable support structures

West Bengal seeks to advance agroforestry by reaching out to various audiences and guaranteeing fair benefits. This initiative encompasses the establishment of nurseries for high-quality seedlings, emphasizing economically significant timber species such as Agarwood, Sandalwood, and Red Sanders, as well as performing trials aimed at improving local livelihoods while maintaining environmental integrity and ecosystem services.

Establishing Coastal Shelter Belt plantations to enhance cyclone resilience

To improve cyclone resilience in the coastal districts of West Bengal, it is crucial to implement extensive mangrove plantations utilizing high-quality planting materials. The integration of technical inputs, including growth promoters and rhizosphere microbes, as well as the use of species like switchgrass and Casuarina for the stabilization of sand dunes, will aid in soil conservation and provide protection against climatic threats.

Government Policies and Programs

West Bengal promotes agroforestry via several initiatives, even in the absence of a dedicated state policy. Notable programs encompass Joint Forest Management, which involves local communities in the conservation of forests; the West Bengal Forest Development Corporation, which encourages the establishment of agroforestry plantations; and efforts led by NGOs that combine fruit tree cultivation with agricultural practices to improve soil fertility and increase farmers' incomes.

The National Agroforestry Policy (2014) and the Sub-Mission on Agroforestry (SMAF)

The National Agroforestry Policy (2014) and the Sub-Mission on Agroforestry (SMAF) establish a comprehensive framework for agroforestry initiatives in India, with the objective of improving productivity, livelihoods, and environmental sustainability. This policy encourages the integration of tree planting with crops and livestock while addressing the demands for resources. The Sub-Mission on Agroforestry (SMAF) is dedicated to providing quality planting materials, enhancing capacity building, and ensuring effective implementation at the state level. Furthermore, the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) promotes afforestation and tree planting as part of its employment initiatives, thereby making a significant contribution to the management of natural resources. In West Bengal, the collaboration among various departments amplifies the ecological advantages of these programs, promoting sustainable agricultural practices and enhancing rural livelihoods.

Financial and Market Support Systems for Agroforestry

Agroforestry financial assistance encompasses cooperative marketing to achieve improved pricing, shared infrastructure, and access to credit facilities. Programs such as SMAF and MGNREGA provide subsidies and grants that support plantation projects. Furthermore, low-interest loans, upgraded Kisan Credit Cards, and insurance options for various tree

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species encourage industry connections and export possibilities, thereby promoting rural development. On farm research activities are conducted at Regional Research Station (Red & Laterite Zone), Bidhan Chandra Krishi Viswavidyalaya, Jhargram, West Bengal.

Enhance agricultural research institutions to promote studies in agroforestry

Small-scale agroforestry producers gain advantages from cooperatives that improve marketing through collective bargaining, shared infrastructure, and direct market access. Cooperatives such as Amul and FPOs facilitate value addition and access to credit. Financial assistance encompasses subsidies (SMAF, MGNREGA), low-interest loans (NABARD), improved KCC, and emerging tree insurance. Public-private partnerships connect farmers to industries and export markets. Strengthening research institutions—particularly in states like West Bengal—necessitates investment in agroforestry departments, laboratories, and technologies. Primary research areas include region-specific systems, climate-resilient species, carbon sequestration, and land rehabilitation. Notable institutions include ICAR-CAFRI, ICFRE, and SAUs like Bidhan Chandra Krishi Viswavidyalaya.

Farmer-Centric Extension Services

Efficient extension services play a crucial role in the adoption of agroforestry. Establish demonstration plots at the block level, organize field schools, and create mobile units to provide education to farmers. Assign trained personnel through KVKs and Panchayats to offer technical assistance. Leverage mobile applications, artificial intelligence, and geographic information systems. Promote collaboration among departments via a State Agroforestry Advisory Committee.

The Integration of Agroforestry and Climate Resilience Initiatives

Incorporating agroforestry into climate resilience initiatives enhances adaptation in at-risk areas such as Bundelkhand, Sundarbans, and Purulia. Important frameworks consist of NAPCC, SAPCCs, MGNREGA, DRR, and GIM. Agroforestry contributes to carbon sequestration, water management, erosion prevention, biodiversity preservation, and income diversification. In coastal regions, drought- and salt-resistant trees such as Casuarina, Avicennia, Neem, Tamarix, Acacia, and Ber offer natural protection and support for livelihoods. Approaches include shelterbelts, mixed cropping systems, mangrove restoration, nursery establishment, and integration with CRA initiatives.

In the Sundarbans of West Bengal, SHGs and FPOs can grow mangroves and Casuarina for poles, honey, and herbal products, thereby fostering ecological and economic resilience.

Conclusion

Agroforestry in West Bengal holds immense promise as a cornerstone of sustainable agriculture and environmental preservation. To fully harness its potential, comprehensive policy support, extensive farmer training, market-driven incentives, tailored financial strategies, and robust networks for research and education are vital. By addressing these areas, agroforestry can evolve into a key component of climate-smart agriculture, enhancing food security, restoring degraded lands, and empowering rural communities for a resilient and sustainable future.

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AGRICULTURE BULLETIN

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Conserve Water and Soil - Let's Preserve It for Tomorrow

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Water and land are the pillars of life, agriculture, and natural balance. Yet human pressure, climate change, and unsustainable behaviors are resulting in serious degradation of these fundamental resources. This bulletin examines the imperative for water and land conservation, and their essential role in food security, biodiversity, and sustainable development. It explores the origins of deterioration, such as unsustainable farming, deforestation, pollution from industry, and urbanization, and provides practical and effective conservation techniques like rainwater harvesting, drip irrigation, contour plowing, cover cropping, and reforestation. The involvement of communities, farmers, and policy makers is highlighted as key in advancing grass roots action and policy for effective environmental protection. The newsletter concludes with a powerful call to action, urging education, engagement, innovation, and advocacy to see the natural resources stay preserved in the long term. Through collaborative stewardship and enlightened action, we can build a greener, more sustainable future.

2: Introduction to Water and Soil Conservation

Water and soil are two of the Earth's most vital natural resources. They form the bedrock of agriculture, ecosystems, and human civilization. Healthy soil supports the growth of crops and plants, regulates water flow, and stores essential nutrients and carbon. Water, meanwhile, is indispensable for drinking, sanitation, farming, and industrial activities. However, despite their critical roles, both water and soil are under increasing threat due to human activities and environmental changes. Abdelhak *et.al.* 2024.

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In recent decades, increased pressure from an expanding world population, accelerated urbanization, and unsustainable land use has caused overexploitation and degradation of these valuable resources. Water levels are declining in most areas with too much groundwater pumping, and several rivers and lakes are becoming irreversibly polluted. Similarly, productive topsoil is being degraded or washed away through improper farming practices, deforestation, and industrial pollution.

Climate change adds to these problems by changing rain patterns, raising the incidence of floods and droughts, and subverting natural processes that keep soil healthy and water in circulation. Unless drastic measures are taken, the trends will further deteriorate, pushing global food production, biodiversity, and people's livelihoods at risk.

Water and soil conservation is not only an environmental imperative—it is a requirement for sustainable development. Successful conservation measures secure agri-productivity, enhance water quality, and develop capacities that can withstand climate shocks. They are also essential for food security, the livelihood of rural communities, and the integrity of natural ecosystems.

Source: https://www.istockphoto.com

Global Context

Evidence of the gravity of this situation is palpable in present-day global figures. As per the Food and Agriculture Organization of the United Nations (UNFAO), about 33% of the planet's soil is already moderately to highly degraded. This has consequences for crop production, adds to the danger of desertification, and hazards future food supplies. On the water front, over 2 billion individuals now reside in areas of high water pressure—numbers likely to expand with climate change and population growth. Ackermann *et.al.*1976.

Visual Suggestion:

Have an infographic displaying:

- Percentage of degraded soil worldwide
- Places experiencing water stress
- Expected effects by 2050 (if nothing is done)

3. Causes of Water and Soil Degradation

Water and soil degradation is an escalating issue fueled primarily by human activities. The first step towards stopping damage and regaining equilibrium in natural systems is comprehension of the underlying causes. Following are the major drivers of this degradation: Blanco-Canqui *et.al.*2008.

1. Unsustainable Agriculture

New farming methods tend to value output over ecological equilibrium. Irrigating land too much creates waterlogging and soil salinization, reducing the land's productivity in the long term. Heavy application of chemical pesticides and synthetic fertilizers destroys useful organisms in the soil and pollutes surrounding bodies of water with runoff. Monoculture—producing the same crop over and over again on the same land—is draining the soil of vital nutrients and lowering biodiversity, thus subjecting the land to pests and erosion.

2. Deforestation

Trees are important in soil structure and water regimes. Root systems of trees hold soil in place, thus preventing erosion, while the leaf canopy cushions raindrops from striking the ground. Once forests are removed for timber, agriculture, or urban settlements, the soil is left without protection against wind and water erosion. Deforestation also hinders groundwater recharge by lowering the amount of rainwater entering the soil, thus exacerbating water shortages.

3. Industrial Pollution

Free-flowing industrial waste—such as heavy metals, oils, dyes, and other harmful chemicals—into the surrounding lands and water bodies heavily contaminates soil and water. Such pollutants kill soil fertility, damage aquatic life, and have serious health implications for human beings and animals. Irrigation using contaminated water can also spread pollutants further onto agricultural land, leading to a vicious cycle of degradation.

4. Urban Expansion

As cities expand, more and more land is paved over with concrete and asphalt. This severely lowers the natural permeability of the land, restricting water entry into the soil and enhancing surface runoff. Runoff tends to have contaminants within it, further compromising adjacent soils and water bodies. In addition, the development of lands from agricultural or forest uses on a permanent basis drastically declines the natural ability of the landscape to support ecosystems.

Visual Suggestion:

A comparative illustration depicting:

- Healthy landscape with forest, pure water, and varied agriculture
- Degraded landscape with erosion, pollution, and deserts

4.Water Conservation Strategies

Conservation of water is crucial to providing sustainable access to clean water for agriculture, domestic consumption, and industry. With climate change, population expansion, and pollution increasingly exerting pressure on freshwater resources, the need arises to implement new and tried approaches towards water management. The following strategies provide effective means of conserving water and ensuring sustainability: Pretty *et.al.*1997.

1. Rainwater Harvesting

Rainwater harvesting is the accumulation and storage of rainwater from roofs, pavement, or catchment surfaces for eventual use. The simple yet effective technique could drastically minimize reliance on groundwater and municipal supplies, particularly in dry and semi-dry areas. Stored rainwater can be utilized for irrigation, landscaping, livestock, or even treated for household use. It is also helpful in replenishing groundwater if it is channeled back into aquifers through recharge pits or percolation tanks.

2. Sprinkler Systems and Drip Irrigation

These new irrigation technologies distribute water to the plant's root zone directly, reducing water loss through evaporation and runoff. Drip irrigation, for instance, makes it possible to control the amount of water and when it is distributed, making it extremely well-adapted for water-scarce areas. Sprinkler irrigation imitates rainfall and offers equal distribution of water to crops. Both approaches improve crop yields using much less water than conventional flood irrigation practices.

Source: pinterest.com

3. Reuse and Recycling

Water reuse is the treatment of wastewater so that it is safe for reuse in non-potable applications like irrigation, industrial cooling, and flushing toilets. Treated effluent or greywater can substitute for freshwater use in industry and agriculture, preserving precious reserves. Water reuse not only saves waste discharge to the environment but also establishes a circular water economy that supports sustainability.

4. Watershed Management

A watershed refers to an area of land which directs rain and snowmelt to creeks, rivers, and lakes. Watershed management means the protection of forests, erosion control, prevention of pollution, and replenishment of natural cover. Sustainable watersheds provide clean water long-term, control flow when it rains and when it is dry, and promote biological diversity. Involvement of communities in

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watershed management enhances water security and resilience of ecosystems.

5.Soil Conservation Strategies

Soil is a dynamic, living system that serves as the basis of agricultural productivity and ecological harmony. Yet, soil is being lost rapidly through erosion, compaction, nutrient loss, and pollution. Conservation of soil not only maintains its fertility but also enables sustainable agriculture and helps reduce climate change. The following are commonly known to be effective in maintaining and restoring soil health:

1. Contour Plowing and Terracing

Contour plowing is cultivating the soil along natural lines of elevation instead of straight rows. This practice reduces water runoff and erosion on sloping ground. Terracing, meanwhile, forms step platforms in hilly areas, slowing down water movement and creating level ground for cultivation. Both methods are particularly useful in mountainous and rainy areas, where they save both water and soil.

2. Crop Rotation and Cover Cropping

Cover crops, like legumes or grasses, are grown between major crops to safeguard soil against erosion, inhibit weeds, and add organic matter. Crop rotation is done by changing the kind of crops cultivated in a field every year to disrupt pest cycles and enhance nutrient balance. These practices not only lower the requirement for chemical inputs but also improve the soil structure and fertility with time.

3. Organic Farming

Organic agriculture prioritizes natural soil management techniques and excludes the application of synthetic fertilizers, herbicides, and pesticides. Organic farming utilizes compost, manure, and biological pest control to enhance the biodiversity and structure of the soil. Organic farming encourages the activity of favorable soil organisms that govern a healthy ecosystem and improve nutrient circulation.

4. Afforestation and Agroforestry

Afforestation refers to planting forest cover in land that was not formerly forested. Agroforestry involves integrating trees or shrubs with crops in the same piece of land. These activities enhance soil strength, enhance water retention, and offer protection from wind and shade. Trees also help in enriching soil organic content and are a long-term measure against desertification.

Visual Suggestion:

Use pictures or symbols to depict:

- Contour-plowed fields
- Cover crops between major crops
- Composting in organic agriculture
- Agroforestry plantation on agricultural field borders

6. Communities, Farmers & Policymakers' Role

Water and soil conservation is not merely a technical problem—it is one of collective responsibility. Solutions need to come from all concerned, involving local communities, farmers, and policymakers for them to be effective and lasting. All these groups have a key contribution in securing these resources and making them sustainable for generations to come. Paper *et.al.*1972.

Community Actions

Environmental stewardship is rooted in local communities. If the residents are aware of the importance of water and soil, they are likely to adopt protective practices. If social awareness campaigns, educational initiatives, and clean-up drives are organized, it can motivate collective action. Everyday habits such as repairing dripping taps, harvesting rainwater, limiting plastic use, and composting kitchen scraps make water and soil conservation a reality at home. Community-driven efforts tend to have a spillover effect, encouraging sustained change in behavior.

Farmer Initiatives

Farmers are the first line of defense for water and soil. Through the implementation of sustainable agriculture practices like organic farming, drip irrigation, crop rotation, and reduced tillage, farmers can reduce damage to the environment drastically while preserving productivity. Joining government-led training programs and conservation programs enables them to obtain newer techniques and subsidies on environmentally friendly gear. Farmer field schools and peer-to-peer exchange of know-how also promote innovation and adaptation to climate-resilient agriculture.

Policy Interventions

There are policies by the government that determine the environment within which conservation would flourish. Financial incentives and subsidies to use water-saving devices, rainwater collection systems, and soil cards for health give people and institutions the power to act. Complementary regulatory actions like prohibitions against illicit deforestation, industrial effluent regulation, and land-use zoning enforcement are also critical. Environmental education in schools and research on sustainable management should also be prioritized by policymakers.

A policy planning approach—integrating agriculture, water, environment, and rural development—can ensure increased conservation efforts are ramped up and institutionalized.

Visual Suggestion:

Design a poster-like visual depicting:

- Members of the community planting trees and cleaning
- A farmer practicing drip irrigation and composting
- Policymakers presenting conservation policies or participating in village meetings

7.Call to Action & Conclusion

Let's Act Today for a Better Tomorrow!

Water and soil conservation is not an ideal yet to be realized in the future—it is an urgent requirement. All individuals have a responsibility, and action in common is the way of retaining our planet's most essential resources.

Educate: Start with awareness-building. Schools, colleges, and community centers must actively create awareness regarding sustainable practices and natural resource conservation.

Participate: Engage in neighborhood initiatives—tree planting campaigns, water body cleans, soil health seminars, and awareness drives can make a real impact.

Innovate: Adopt and advocate the use of green technologies such as drip irrigation, organic composting, and rainwater harvesting systems to provide intelligent resource management.

Advocate: Back policies that safeguard our environment. Take a stand for responsible land use, tighter pollution regulations, and conservation rewards.

Conclusion:

Soil and water are not renewable resources. Lost, they can never be restored for generations to come. Their conservation is not merely a matter of choice- it is both our moral responsibility and duty.

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Sustainable crop production with various water saving

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Introduction

Sustainable crop production involves growing crops in a manner that preserves the environment, safeguards biodiversity, and maintains the quality of agricultural produce. It emphasizes long-term productivity without increasing dependence on chemical inputs such as synthetic fertilizers and pesticides. By focusing on practices like maintaining soil health through organic matter, using integrated pest management, and minimizing chemical pesticide use, sustainable agriculture aims to create a resilient and self-sustaining system. It also promotes biodiversity, ensures food safety and quality, and enhances the nutritional value of crops by using natural soil enrichment methods. The overarching goal is to meet the current food and fiber needs of society without compromising the ability of future generations to meet theirs.

Importance of water in agriculture

Water is both a renewable and exhaustible resource, making its sustainable management crucial. Among all natural resources, water plays the most vital role in ensuring sustainable agricultural development. In particular, the sustainable use of irrigation water is a key priority, especially in regions facing water stress. However, increasing socio-economic pressures and the impacts of climate change are placing significant constraints on the amount of water available for agriculture. If environmental mismanagement continues, the dependence of agriculture on irrigation is expected to grow even further. The ability of farmers to access and efficiently utilize water is a critical factor in maximizing crop yields. As such, water access is a significant determinant in measuring a region's food security and plays a vital role in the food security index.

Water scenario of India

India, with a population of over 1.27 billion and a land area of approximately 3.29 million km², receives an average annual precipitation of 1190 mm, translating to about 4000 billion cubic meters (BCM) of water. However, this rainfall is highly uneven across regions and seasons, with nearly 80% of the annual precipitation concentrated within just 3 to 4 months and spread over approximately 80 rainy days per year. The Brahmaputra-Barak-Ganga river system alone contributes around 60% of the country's surface water resources. Despite the substantial total precipitation, only 1123 BCM is deemed utilizable 690 BCM from surface water (65% utilized) and 433 BCM from groundwater (57% utilized). According to India's water budget, out of 400 million hectare meters (m ha m) of precipitation, 215 m ha m infiltrates the soil, contributing to 165 m ha m of soil moisture and 50 m ha m of groundwater recharge. Meanwhile, 70 m ha m is lost to evapotranspiration, and 115 m ha m becomes surface runoff. Despite these resources, about 54% of India's population faces high to extremely high water stress, largely due to overuse and inefficient water management. Agriculture is the largest water consumer, accounting for 85.3% of total usage, followed by domestic use (6.6%), other uses (6.5%), industry (1.3%), and energy (0.3%). Alarmingly, per capita water availability has been steadily declining from around 1900 m^3 in 2001 to a projected 1350 m^3 by 2031, reflecting increasing water scarcity. Simultaneously, water demand is rising sharply, with total demand expected to surge from approximately 1800 BCM in 2010 to nearly 3000 BCM by 2050, driven mainly by irrigation, household needs, and industrial growth. This growing mismatch between demand and supply underscores the urgent need for water conservation, efficient utilization, and enhanced storage infrastructure to ensure long-term water sustainability.

Water saving technologies

Effective water management can be achieved through evidence-based solutions, particularly when integrated with complementary technologies related to land, soil, and crop management. Long-term sustainability will depend on the successful combination and adaptation of these proven practices. Several adoptable technologies have been identified that are suitable for different Agro-Climatic Zones (ACZs), and these should form the foundation for developing a comprehensive and integrated water management policy framework at the state level.

Water Harvesting and Storage

- **Rainwater harvesting**

  It facilitates the storage of rainwater for future use, contributes to groundwater recharge, and serves as a cost-effective method for water conservation. Recognizing its importance, the Hon'ble Prime Minister of India launched the "Jal Shakti Abhiyan: Catch the Rain – Where it Falls, when it Falls" on 22nd March 2021 to promote rainwater harvesting and sustainable water management practices across the country.

- **Farm ponds and water harvesting structures**

  Water harvesting structures constructed in low-lying areas serve as effective means to store surface runoff, helping to replenish groundwater reserves. The water collected in these structures can be utilized for life-saving irrigation, especially during dry spells, ensuring crop survival. Additionally, the presence of impounded water enhances the soil moisture regime in the surrounding areas, leading to improved crop productivity and further contributing to groundwater recharge.

- **Check Dams**

  Structures built across stream flows are designed to reduce the velocity of runoff water, thereby minimizing erosion and promoting greater water infiltration. These constructions are generally permanent in nature and play a key role in water conservation by retaining and regulating water movement. Additionally, sluices, spillways, and other regulatory structures installed within drainage systems help to control and manage the flow of excess water, preventing overflow and ensuring efficient water distribution for agricultural and ecological purposes.

Irrigation Methods

- **Furrow Irrigation**

  Furrows are narrow, parallel channels designed to allow water to infiltrate into the soil and spread laterally through capillary action, thereby maintaining soil moisture and improving overall water use efficiency. This method is particularly effective on gentle slopes ranging from 0.2% to 0.5%, making it ideal for areas with mild terrain. Furrow irrigation is especially well-suited for root and tuber crops, as it ensures consistent moisture availability around the root zone, promoting healthy growth and higher yields.

- **Alternate furrow irrigation**

  Alternate Furrow Irrigation (AFI) is a water-saving technique in which only one of every two neighbouring furrows is irrigated during each watering cycle, alternating the irrigated furrows in the next cycle. This method significantly enhances water use efficiency by reducing the volume of water applied while still maintaining sufficient soil moisture for crops. AFI is commonly practiced for crops like potato, mustard, and various vegetables, where it supports healthy growth without compromising yield. The technique has demonstrated notable water savings across different crops, for example, 45% for sugarcane, 27–29% for maize, 27% for cotton, 16% for tomato, and 12% for sunflower, making it a practical and sustainable option for areas facing water scarcity.

- **Alternate Wetting and Drying (AWD)**

  Reducing the percolation rate from crop fields is an effective strategy for both water conservation and groundwater protection. When percolation is minimized, it significantly decreases water loss resulting in 30–60% water savings—and improves water use efficiency. Additionally, controlling percolation helps to limit the leaching of nitrates, heavy metals, salts, nutrients, and pesticides into the groundwater, thereby preserving its quality. Studies indicate that percolation can be reduced by 50–80%, making this approach a vital component in sustainable water and environmental management practices. A comparison between Alternate Wetting and Drying (AWD) and conventional irrigation methods reveals the superior efficiency of AWD in terms of water use and productivity. For rice seedlings transplanted at 14 days, AWD required only 17.7 m^3 of water and achieved a water productivity of 1.70 kg/m^3, whereas conventional irrigation used 23.9 m^3 with a lower productivity of 1.35 kg/m^3. Similarly, for 21-day-old seedlings, AWD used 34.8 m^3 of water and achieved 1.65 kg/m^3 productivity, compared to 42.3 m^3 and 1.25 kg/m^3 under conventional practices.

- **Micro-irrigation**

  Adopting efficient irrigation methods such as sprinkler and drip systems significantly enhances water use and crop productivity. Sprinkler irrigation can save 30–50% of water, while drip irrigation offers even greater savings up to 80%. These systems improve water use efficiency by 60–70%, leading to a 30–40% increase in crop yield. Moreover, they contribute to fertilizer savings of around 40%, as nutrients are applied more precisely. Another advantage is the ability to cultivate crops even in saline soils, making these technologies essential for sustainable and resource-efficient agriculture.

- **Bottle irrigation**

  It is a simple, low-cost, and highly effective method of providing continuous moisture to plants, especially in water-scarce areas or for small-scale home gardening. In this technique, a bottle filled with water is inverted and inserted near the root zone of the plant. The water is gradually released into the soil, ensuring that the plant remains adequately hydrated throughout the day. This slow and steady supply of water minimizes wastage due to evaporation or runoff and helps maintain consistent soil moisture, which is crucial for healthy plant growth. It is particularly useful during dry spells or in areas with limited access to irrigation infrastructure.

- **Pitcher Pot Irrigation**
  It is a traditional and efficient method where a porous clay pot is buried near the plant's root zone and filled with water. The water slowly seeps through the pot walls, directly reaching the roots, which ensures deep and effective watering. This method significantly reduces evaporation losses and keeps the soil consistently moist. It is especially suitable for arid and semi-arid regions, promoting water conservation while supporting healthy plant growth.
- **Bamboo Drip Irrigation**
  In this efficient water distribution system, approximately 18–20 liters per minute of water flowing from the main channel is gradually reduced to just 10–80 drops per minute at the end of the network, allowing for precise and controlled irrigation. Water sourced from an uphill location is tapped and delivered without leakage, ensuring that crops receive adequate moisture while significantly reducing leaching losses. This method not only helps in conserving water but also improves crop yields by supplying water directly to the root zone. Additionally, it enhances the infiltration capacity of the soil, promoting better moisture retention and healthier plant growth.

Soil and Water Conservation Technologies

- **Terrace**
  Bench terraces are earth embankments constructed across the natural slope of the land to reduce surface runoff and minimize soil erosion. These terraces are especially effective on steep slopes ranging from 16% to 33%, where they transform otherwise unproductive hilly terrain into arable and irrigable fields. By capturing rainfall and holding it within the terrace structure, they significantly increase water retention, promoting better soil moisture availability and supporting sustainable agricultural practices in sloped and erosion prone areas.
- **Contour bunding** It is a technique used on gentle slopes ranging from 2% to 6%, designed to capture and retain rainfall before it is lost through surface runoff. This practice helps improve water infiltration and soil moisture, making it beneficial for sustainable land and water management in sloping agricultural areas.
- **Earthen bunds**
  This technique helps reduce the velocity of runoff, thereby increasing the retention time of rainwater. As a result, more water is allowed to percolate into the soil, enhancing groundwater recharge and soil moisture.
- **Semi-circular bunds**
  Semi-circular bunds, or demi-lunes, are crescent-shaped earth structures built along contours in semi-arid regions to harvest runoff and support young tree saplings. Planting pits within these bunds are filled with topsoil and organic manure, which enhances nutrient availability and helps retain soil moisture for healthy plant growth.
- **Land shaping**
  This approach involves the creation of irrigation resources by harvesting excess rainwater, which not only ensures water availability during dry periods but also helps manage soil salinity by reducing the influence of a shallow groundwater table. Additionally, it plays a vital role in improving drainage congestion, thereby enhancing land productivity and supporting sustainable agricultural practices.
- **Mulching**
  This method reduces runoff and enhances water infiltration into the soil, helping to retain soil moisture and reduce erosion. It also lowers root zone temperature, suppresses weeds, and supports crop growth during moisture stress conditions.

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- **Minimum Tillage**

  Minimum tillage enhances soil health by allowing crop residues to decompose in place, enriching the soil with organic matter. The presence of vegetation and natural channels formed by decaying roots improve water infiltration, while reduced use of heavy machinery minimizes soil compaction, promoting better root growth and soil structure.

- **Paira cropping**

  Paira cropping involves sowing crops like linseed, khesari, or lentil immediately after the harvest of the main crop, particularly in cases of terminal drought caused by early monsoon withdrawal. This practice enables farmers in rainfed regions to effectively utilize the residual soil moisture. Additionally, it promotes cropping system diversification by integrating pulses and cereals, thereby reducing the risk of crop failure and enhancing overall resilience in farming.

- **Use of Anti-Transpirants**

  Anti-transpirants are materials or chemicals applied to the leaf surface of plants to reduce water loss through transpiration, thereby helping to maintain plant growth and productivity during stress conditions such as short-term droughts. They are especially useful in managing intermittent droughts of 6–10 days during critical stages of crop development. Anti-transpirants are classified into four main types based on their mode of action: stomata-closing types (e.g., Phenyl Mercuric Acetate - PMA @ 10^{-4}, Atrazine), film-forming types (e.g., Mobileaf, Hexadecanol, Silicone, Oils, Waxes), reflecting types (e.g., Kaolin 5%, China clay, Calcium bicarbonate, Lime water), and growth retardants (e.g., Cycocel - CCC). These substances collectively help conserve moisture and minimize crop losses during dry spells.

Conclusion

Farmers have access to a variety of management strategies to enhance water productivity while safeguarding their livelihoods. Maximizing irrigation coverage requires the capture of runoff, replenishment, and judicious extraction of groundwater using efficient irrigation techniques. However, it is important to recognize that realizing true water savings is often complex and highly context-specific, influenced by local conditions. To ensure significant and lasting impact, planning and analysis must be conducted at the district or river basin level, considering regional variations in water availability and usage.

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Women and Agroecology
Two halves of the better future

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Introduction

Lord Brahma has created two genders, to be impartial in the universe, have equivalent esteem on each other, indistinguishably execute their obligations and effort coequally for expanding their build up on the earth. Women during Vedic period enjoyed equal status with men in all aspects of life. Scriptures such as Rig veda and Upanishads mentioned the many notable women in history. In approximately 500 B.C the status of women began to decline and is still continuing. There is much discrimination with respect to gender in many categories ranging from birth to death. There is a literacy gap of 16.6% between male and female, where 82.14% and 65.46% has been recorded with male and female respectively. Less than half of the women in India are unable to fulfil their dream of higher education. Women earn only 62% of the men's salary for the equal work. More than three fourth of the agricultural produce is coming out of the women sweat.

Despite the low profile women posses with respect to most things that matter, they play a decisive and fundamental part in the wellbeing and prosperity of the society and nation as a whole. As we researchers of agriculture field experienced the importance of women in agroecology as growers, labourer, educators and administrators at first hand and realised the motive force that inspired their progress in farming is primarily due to the following reasons

Change in life style

Literacy rate and the employment rate of women in rural as well as urban areas are increasing at an alarming rate. The life of the women has been transforming from self dependent to self-independent, who are in search of self esteem. During this modern and competitive era both the men and women should equally work to advance the economic security. Women equally working hard to attain this, where once they were confined to kitchen. In this regard they have chosen agriculture and allied sectors

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as their livelihood. Participation of the women in the fields of food production, food processing, dry flower industry, landscaping industry, cut flower, nursery production and preparation of value added products *viz*., frames, baskets, bamboo products, fresh and dry flower bouquets has gained the momentum. Women from many agricultural universities as scientists and researchers have been associated with the development of agriculture in terms of education and encouraging the women in Agroecology. The tribal women of the Dang forest from Gujarat have explored their varieties of value added products of bamboo and wild flora. We came across many conferences and workshops where women from tribal areas, villages and even urban areas are actively participating in the training programmes to learn and to generate self-employment.

Women psychology

Women are better concerned about inside resource management issues, they have a positive opinion about farming, soil conservation and the environment, all of which have major influence on strategic planning in the ecology. The intuitive patience of the women helps in making a holistic approach towards matters concerning the conservation of Agroecology, as the old adage goes “Patience is a virtue”. Women can be skilful decision makers, successful coordinators and talented at taking up new technologies as an answer for burning and upcoming challenges. They build up their minds to conceive the negative changes regarding Agroecology and ways to combat them. Many of the farmer men around the India converting their agricultural land in to corporate land in order to fly from the fluctuations of the agriculture, are left in the debt, even in this context many women farmers are taking an initiative step to feed the nation and the world, showing that they can equally tackle and manage the issues of the Agroecology. Recent studies on progressive farmers revealed that both men and women farmer have equal potential to be developed in to commercial farmers if opportunities for self development are available.

Hereditary

If all humans on the earth would have thought that the farming is hereditary like other professions, we might not in the condition that we are facing now. India is facing much poverty where 30% people are in the capture of hunger and malnutrition. Our indigenous farming practices are diminishing. Many women from the farming background especially in the tribal areas and villages are continuing their job as seeds of farming has been digested in their blood. They are following the organic farming practices. Even women with farming background in urban areas continuing their pride in the form of modern horticulture, nursery production and landscape industries, which in turn create employment to the others.

Self sufficient

Self sufficiency is an essential aspect in the wellbeing for every person. Many families in India are far away from the quality life in terms of education, health, economic and social security. These realities demonstrate the critical need for advocacy programs and strategies that increase opportunities for women and the families to move from poverty to living wage jobs and economic security. Sometimes farmer suicides and poor family conditions drive the women towards the agriculture where they can get self employment and can lead their family in a better way. Women can show much horizontal and vertical diversification in the farming.

Growing awareness about food nutrition

As a mother and as a cook women are well aware about the nutritional security of the family as well as the nation. Progress in woman’s education access and better involvement increased food availability and health advance. India is one among the countries with high global hunger index, to mitigate this government supplying food material to the midday

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meals programme, where the school children are provided with nutritious food. Women being innately tolerant and rational when concerned about ecology and agriculture have more liberal visions. That persistent feeling of the motherhood is probably the reason that inspires the women towards implementing more practical and tenable solutions that address the rapidly declining ecological health and the increasing pressure of malnutrition.

Positive hand by Government

Government has been providing the subsidies at a higher rate and with less interest rate especially to the women farmers to encourage their growth and development. Women in some states started practicing the group/community farming. Schemes like self help groups, DWACRA, mahila sankshema yojana etc, are encouraging them to initiate the small scale industries, marketing of the agricultural produce and even processing of food products.

Women as agricultural faculty, researchers and scientist

Women as educators leave an unparalleled mark on the society as they tend to be more parental in their outlook towards students thereby inculcating ethical values of immense worth. These do not stop at what text books have to offer, but take an extra effort to implant a better social and environmental outlook towards the challenges faced by the nation, thereby encouraging the students to develop a creative and holistic attitude that contribute to nation's wellbeing henceforth.

It's an endeavour to focus on the motive forces that draw women towards Agroecology. To conclude, we researchers of agriculture inspired by the heritage of it in India and by the positive energy greenery fill us with, are all set to get our hands muddy to see a positive change come up in terms of climate resilient and sustainable farming and we are willing to stay honest to the noble profession.

Women involved in processing and farm activities

Women employed in Hi-Tech horticulture

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Therapeutic Beauty: A Guide to Grow Aromatic plants in urban cities

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Introduction

By 2025, our planet struggles under the weight of its own waste. The essentials of life—air and water—are now dangerously compromised, a direct consequence of our modern advancements. Earth, much like a chain smoker, is suffocating from the constant assault of pollution. A key culprit is fine particulate matter (PM2.5), an insidious threat causing premature mortality and widespread disease. India's vibrant heart, Delhi, now pales under alarmingly high PM2.5 levels, reaching an astounding 107.1 µg/m³. This crisis isn't confined to Delhi; other metropolitan hubs like Chennai, Bengaluru, Mumbai, and Kolkata are equally affected. The path forward is clear: we must commit to making our surroundings significantly greener.

Another issue in this modern world is stress and anxiety. In this fast-paced world, people are tired. Mental issues have become increasingly common due to socioeconomic pressure, lifestyle changes etc, In this post-pandemic world, stress and anxiety symptoms scale out to be 25.2% and 20.5% respectively. Most of the symptoms were found among the youngsters (60%).

In our polluted 2025 reality, instant fixes are futile. Mass tree planting and masking offer no overnight salvation. True change begins individually. This article guides you on gradually greening your own home, even with limited space. Discover how to select, manage, and beautify aromatic plants, unlocking their benefits and enhancing your living environment.

Getting started, choosing the right plants for you:

Integrating aromatic plants in your day-to-day life can be unique and keep you refreshed all day. The first step is to choose the right plants of your choice. There are abundant aromatic plants available. They can be either indoor or outdoor, flowering or nonflowering, shrubs or climbers etc, The choice is based on the place you live. If you have enough space around your home, you can go for trees like Pagoda or Champaca and shrubs like Roses and Basil. If you are living in an apartment you can go for potted plants and hanging baskets. Utilise your balcony effectively and make it green. Let's see various aromatic plants you can grow.

Outdoor plants:

Trees:

Trees are the inevitable being that holds the secret of this world. Let's see the aromatic trees below;

Plumerias; This genus comprises the most beautiful trees. They are called pagodas or temple trees or frangipani. Plumeria rubra is a winter deciduous tree of medium height. It features highly fragrant red flowers. Plumeria alba produces white coloured flowers. Another species Plumeria pudica is quite familiar in Singapore. Their leaves are uniquely spoon-shaped, similar to snakes. Dhandapani et al., 2019 reported that plumeria flowers contain 43 VOCs including benzyl nitrite. Plumeria thrives best in full sun exposure and well-drained soil. Pruning should be done to maintain the shape.

Champaca; Champak trees are widely known for their fragrant flowers, There are different species of their tree; Magnolia champaca commonly called swaran champa. They grow up to 30m bearing fragrant yellow coloured flowers. Flowers usually appear in the second week of May. Another species Magnolia grandiflora flowers white fragrant flowers. They are commonly called bara champak. Pterospermum acerifolium, called kanak champa, forms a conical crown. Flowers that are yellow with long petals appear in April and up to June.

Camphor tree; Cinnamomum camphora, the camphor tree is a large evergreen tree known for its distinctive aroma. This tree produces a camphor aroma when the leaves are crushed. It exhibits chemical variants; camphor, linalool, 1,8-cineole, herolidon, safrole and borneol. Anti-inflammatory, antimicrobial, and pain-relieving properties, while linalool and borneol offer calming and soothing effects.

Shrubs:

Shrubs are herbaceous woody perennials that grow up to 1-3 m high. They are planted outdoors with maximum space. They take up the garden boundary wall and provide liveliness to the garden. They also used to screen unwanted places in the garden.

Vertex or vennochi; Vitex negundo is a large aromatic shrub, found growing in all warmer parts of India. It is used as a diuretic, expectorant, anthelmintic, febrifuge, tonic and used as a demulcent in dysentery. It prefers well-drained soil with a pH between 6.0-7.5. It can be grown in temperate and tropical conditions and can withstand low temperatures. It possesses viridifolia, β-caryopyllene, sabinene and other volatile compounds that are antidepressant and anxiolytic.

Musk Mallow; Abelmoschus moschatus is an erect medium-sized herb native to India. It is popularly known as ambrette. reported that the seeds contain palmitic acid, oleic acid and linoleic acid. Essential oil is extracted from the seeds used in luxury perfumes and cosmetic products also used to make incense sticks. It is a hardy crop grown in full exposure to the sun.

Patchouli; Pogostemon patchouli is an aromatic herbaceous perennial plant. It can be grown in hot and humid conditions and also in hill stations up to an elevation of 1500m. Patchouli oil is used in aromatherapy to relieve stress and depression. It possesses volatile compounds like patchoulol, patchoulene, selinine etc. Its fragrance is similar to wine and helps in sharpening intelligence, attention and intuition.

Climbers; Climbers add depth to any type of garden. They are used to grow over walls, arches, pergolas,

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pillars, bowers etc. They can make your home unique from others.

Honeysuckle; Lonicera japonica, commonly called a Japanese honeysuckle plant, is an evergreen and quick- growing climber. They produce white flowers that change to yellow over time. They are highly fragrant and can be used for a trellis. It cannot tolerate high temperatures so use it in shade conditions.

Madhavilata; Hiptage benghalensis also called as madhavilata is one of the oldest climbers that originated in India. It is a heavy climber and produces creamy white flowers in February and March. It needs regular pruning to maintain its shape.

Potted plants: Potted plants are important features in terrace gardening that limit space. They occupy small areas and are best suited for people living in apartments. Let's see what aromatic plants can be grown in pots.

Chamomiles; Matricaria chamomilla also called babuna is a recent age medicinal plant. Petronilho et al., 2012 reported that more than 26 countries have recognised chamomiles as medicinal plants. Chamomile tea is very popular nowadays. Essential oils taken from them are used to make skin care products, toothpaste. There are two types of chamomile: Roman chamomile and German chamomile. German chamomile is annual and cultivated widely around the world. While Roman chamomile is used for ground covers.

Choose pots that drain out quickly. Use sandy loam soil as it can't tolerate waterlogging conditions. Chamomiles require 5-6 hrs of sun exposure. Keep it in partial shade during afternoons. Weekly watering.

Dhavana; Artemisia pallens is a delicate, erect and branched annual herb 45-60 cm tall covered with greyish white tomentum. Dhavana requires bright sunshine and mild watering. It's a delicate plant and cannot withstand waterlogging. Seedlings are transplanted at a height of 10-12 cm. Dhavana leaves are used to extract essential oils. It contains davanone, caryophyllene, and linalool. The characteristic odour is due to davanafurans; they constitute 0.8% of the essential oil.

Indoor plants:

Coleus; Coleus aromaticus is also known as karpooravalli in Tamil and patta ajwain in Hindi. It is a potential antibacterial activity and a free radical scavenging antioxidant. It is a succulent aromatic plant that can grow 20-30 cm long with thick stems. The leaves possess a fragrance similar to menthol. Wadikar and Patki, 2016 reported that leaves contain 3.75% terpinolene and 3.20% alpha pinene.

Melissa; Melissa officinalis called lemon balm due to its typical lemon flavour. They can tolerate temperatures up to 15-35°C. The leaves are used to extract essential oil.

Wax plant; Hoya carnosa is known for its ornamental waxy flowers. It is an epiphytic climbing plant perfect for hanging baskets. Each species has a distinct aroma. According to Rasas et al, and Vander Berg et al., H. vittelinoides gives citrus aroma, H. carnosa gives chocolate and H. cagayanensis gives spicy aroma.

Screw pine; Pandanus amaryllifolius called pandanus is known for its aromatic leaves. It is used to flavour rice, beverages and desserts. In Thai cuisine, pandanus leaves are used to wrap the sticky rice and cook it under steam. It can be propagated through cuttings or suckers. They produce aerial roots to absorb moisture.

Other indoor aromatic suggestions are Vicks plant, false incense, rosemary, thyme, scented geraniums, and spider lilies.

Day scented plants	Night scented plants
Rose 'felisia'	*Mirabilis jalapa*

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Rose 'prosperity'	*Oenothera caespitosa*
Cupressus macrocarpa	*Abronia fragrans*
Rose 'penelope'	*Cestrum parqui*
Thuja plicata	*Daphne laureola*
Rose 'zephrine'	*Hesperia matronalis*
Chamaecyparis lawsoniana	*Linniaea borealis*

Table. 1 List of plants based on flowering time
Horticultural therapy and its benefits:

Horticultural therapy involves growing plants to improve mental well-being. According to the American Horticultural Therapy Association, it is the engagement of a person in gardening and plant-based activities, to achieve specific therapeutic goals. Some of the techniques used are sensory-oriented plants, hugging trees, grand entrance, gravel paths, vertical gardening, and water gardens with ponds. This therapy is based on sensory aspects like colour, texture and fragrance. Our nose recognises the scent around us and generates an electrochemical signal to the brain's limbic system, subsequently leading to emotional changes.

Volatile compounds produced by the plants can reduce tension, anxiety, stress, trauma and give an optimistic feeling. Linalool, Limonene, β-Myrcene, Fenchyl acetate, β-Selinene, Verbenone and γ-Terpinene can reduce our anxiety called anxiolytic compounds. Geraniol, Eugenol, and Camphene are called antidepressant compounds.

Cui et al., 2025 reported that volatile compounds produced by the Vicks plant (Plectranthus tomentosa) reduced the rapid heart rate. The brain produces α waves when our body is in a relaxed state achieved through meditation. Cui et al., 2025 also reported that coriander's (Coriandrum sativum) volatile compounds significantly increase the α waves thus promoting calmness. Another foliage plant basil (Ocimum basilicum) also does this. It helps to regulate the mental, emotional and physiological state of humans.

How to set up a sensory garden?

It symbolises the 5 senses, vision, touch, taste, hearing and smell. You can create it anywhere with simple gardening designs.

Outdoor:

To create an outdoor aromatic garden follow the guidelines mentioned here. Always plant sun- loving plants in the east direction and shade-tolerant plants in the south direction. Don't use monochromatic colours. Give contrast by adding different colours. Give a balance and rhythm using symmetrical design.

Fig.1 Layout of an outdoor garden

1. Nyctanthes arbour-tristis; 2. Thuja occidentalis; 3. Zoysia japonica; 4. Millingtonia hortensis; 5. Camphora officinarum; 6. Ocimum tenuiflorum; 7. Plumeria rubra; 8. Magnolia champaca; 9 (a). Cestrum nocturnum, (b). Ixora odorata; 10. Pandanus pyramidalis

The layout shown below depicts an idea about how to modify your terrace. This plan illustrates the terrace of an apartment.

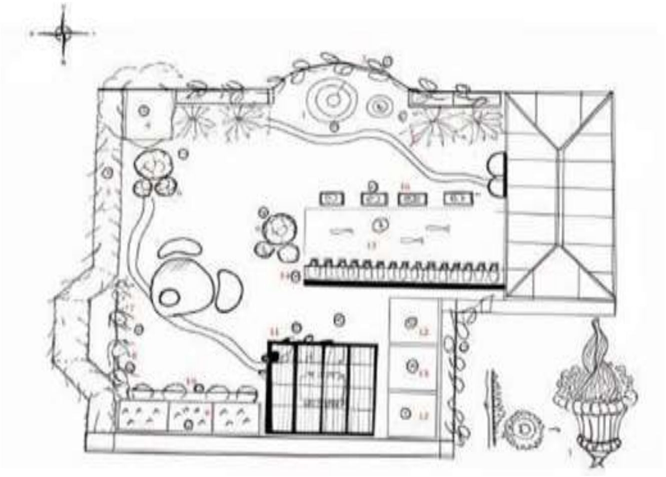

Fig.2 Layout of terrace garden

1. Thuja plicata; 2. Lematis paniculata; 3. Lycoris radiata; 4. Plumeria rubra dwarf; 5. Cananga odorata; 6. Matricaria chamomilla; 7. Hoya carnosa; 8. Pelargonium graveolens; 9. Hedychium coronarium; 10. Melissa officinalis; 11. Clematis paniculata; 12. Cestrum nocturnum; 13. Ixora odorata red ; 14. (a) Thymus vulgaris, (b) Mentha aquatica, (c) Coleus scutellarioides, (d) Salvia rosmarinus, (e) Ocimum basilicum var. Purpurascens; 15. Nymphaea odorata; 16. Cymbopogan flexuosus

Conclusion

In an age of urban pollution and rising stress, aromatic plants offer a natural path to wellness. These plants not only purify the air but also uplift mood with their calming scents and therapeutic benefits. Whether in gardens, balconies, or indoor spaces, species like Plumeria, Chamomile, Patchouli, and Melissa officinalis help create soothing environments. Horticultural therapy and sensory gardening promote mental well-being and reconnect us with nature. As cities expand, integrating aromatic greenery into daily life can transform our surroundings into peaceful, healthful sanctuaries—encouraging a greener, more balanced way of living.

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Enhancing Soil Fertility for Sustainable and Climate-Smart Agriculture: Pathways to Resilient Food Systems

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Soil fertility is essential for agricultural productivity and global food security, yet about 33% of the world's soils are moderately to highly degraded due to nutrient depletion, erosion, and unsustainable practices. Climate change worsens this by disrupting rainfall and increasing extreme weather, potentially reducing crop yields by 10–25% by 2050. This paper emphasizes the importance of enhancing soil fertility through sustainable and climate-smart agricultural practices that improve nutrient cycling, water retention, and biological activity. Balanced nutrient management, organic amendments, crop rotations, and precision agriculture can increase nutrient use efficiency—currently often below 50%—and reduce greenhouse gas emissions, especially nitrous oxide. Enriching soil organic matter improves water retention by 20–30%, buffering crops against drought. Soil carbon sequestration could offset up to 30% of global annual CO_2 emissions. Technologies like soil health cards, remote sensing, and biofertilizers support sustainable nutrient management. However, challenges like limited awareness, access, and high costs remain. This paper recommends integrated nutrient management, promoting biofertilizers, expanding precision agriculture tools, and strengthening policies and education. These strategies align with climate-smart agriculture goals to sustainably boost productivity, build resilience, and mitigate climate change impacts for future food security.

Introduction

Soil fertility is the cornerstone of agricultural productivity, directly influencing crop yields and food security worldwide. According to the Food and Agriculture Organization (FAO, 2021), nearly 33% of global soils are moderately to highly degraded due to nutrient depletion, erosion, and unsustainable land management practices. This degradation threatens the livelihoods of over 2 billion people who depend on agriculture. Healthy, fertile soils provide essential nutrients, water retention, and biological support needed for robust crop growth. Climate change intensifies these challenges by altering rainfall

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patterns, increasing temperatures, and triggering extreme weather events like droughts and floods, which exacerbate soil degradation (IPCC, 2022). For example, rising global temperatures could reduce crop yields by up to 10-25% by 2050 in some regions if soil health is not maintained (Lal, 2020). Moreover, unsustainable farming practices contribute nearly 10% of global greenhouse gas emissions, further driving climate change (Smith et al., 2019). In response, sustainable and climate-smart agricultural practices that enhance and maintain soil fertility are vital. These approaches improve soil resilience, increase carbon sequestration, and support stable food production under changing climatic conditions, thus securing the future of global agriculture.

Soil Fertility

Soil fertility is the ability of soil to supply essential nutrients for healthy plant growth and sustainable crop production. Key nutrients include nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, and micronutrients like zinc and iron, which support vital plant functions such as photosynthesis and enzyme activity. Fertility is governed by soil's physical, chemical, and biological properties. Physically fertile soils have good structure, texture, and water-holding capacity. Chemically fertile soils maintain balanced pH and sufficient nutrient availability. Biological fertility relies on soil organisms—bacteria, fungi, and earthworms—that enhance nutrient cycling and organic matter decomposition. Globally, about 33% of agricultural soils are degraded due to nutrient loss, erosion, and poor management (FAO, 2021). Such degradation reduces crop yields and threatens food security. For example, nitrogen deficiency alone may reduce cereal yields by up to 50% (Smith et al., 2019). Indicators of soil fertility include organic matter content, pH, nutrient levels, cation exchange capacity, microbial biomass, and enzyme activity. Regular monitoring of these indicators helps guide effective soil management, ensuring long-term productivity and resilience to climate change.

Soil Fertility and Sustainable Agriculture

Balanced nutrient management is fundamental to sustainable agriculture, ensuring that crops receive the right amounts of essential nutrients without causing environmental harm. Imbalanced or excessive fertilizer use can lead to nutrient leaching, groundwater contamination, and greenhouse gas emissions, particularly nitrous oxide, a potent climate-warming gas. Globally, nutrient use efficiency in cropping systems is often below 50%, indicating substantial nutrient losses and inefficiencies (Liu et al., 2020). Sustainable nutrient management practices aim to optimize input use, increase nutrient use efficiency, and reduce environmental footprints. Organic matter plays a pivotal role in maintaining soil fertility by enhancing soil structure, water retention, and nutrient availability. It serves as a reservoir of nutrients released slowly through microbial decomposition, supporting continuous plant growth. Soils rich in organic matter also sustain higher microbial biomass and enzymatic activity, which are vital for nutrient cycling and soil health. Several agricultural practices improve and maintain soil fertility sustainably. Crop rotation disrupts pest cycles, improves nutrient balance, and reduces soil erosion. Cover crops prevent nutrient leaching, fix atmospheric nitrogen (in the case of legumes), and increase soil organic carbon. The addition of organic amendments like compost and manure replenishes nutrients and enhances microbial activity. Studies show that integrated nutrient management combining organic and inorganic fertilizers can increase crop yields by 20–30% while improving soil fertility and reducing environmental impact (Mahajan et al., 2021).

Soil Fertility in Climate-Smart Agriculture

Climate-Smart Agriculture is an integrated approach designed to increase agricultural productivity, enhance resilience to climate change, and reduce greenhouse gas emissions (FAO, 2013). The principles of CSA revolve around three main goals: sustainably increasing agricultural productivity and incomes, adapting and building resilience to climate change, and reducing or removing greenhouse gases where possible. Soil fertility improvement is a cornerstone of CSA as it directly influences crop productivity and the soil's ability to withstand climatic stresses. Improving soil fertility mitigates climate change impacts by enhancing nutrient cycling, increasing biomass production, and supporting microbial activity critical for soil health. Healthy soils with balanced nutrient availability enable crops to better tolerate drought and flood events, which are becoming more frequent due to climate change. For instance, soils with higher organic matter content can retain 20-30% more water, reducing drought stress and improving crop survival rates during dry spells (Lal, 2020).

Table 1. Key Soil Fertility Practices and Their Climate-Smart Benefits

Practice	Climate-Smart Benefits	Reference
1. Balanced Nutrient Management	Prevents nutrient runoff, reduces greenhouse gas emissions	Bhattacharyya et al., 2015
2. Organic Matter Addition	Enhances soil carbon sequestration, improves moisture retention	Smith et al., 2019
3. Crop Rotation & Cover Crops	Increases biodiversity, reduces pest pressure, maintains soil fertility	Mishra et al., 2018
4. Soil Testing & SHC Scheme	Enables precise fertilizer application, reduces input costs	Singh et al., 2022
5. Precision Agriculture	Optimizes input use, minimizes environmental footprint	IPCC, 2022
6. Biofertilizers	Promotes beneficial microbes, reduces chemical fertilizer dependence	Bhattacharyya et al., 2015

Enhancing soil carbon sequestration is a key strategy in CSA, as soils globally have the potential to sequester approximately 2.6 gigatons of carbon annually, offsetting about 30% of global annual CO2 emissions from fossil fuels (Paustian et al., 2016). Practices such as cover cropping, reduced tillage, and organic amendments increase soil organic carbon, improving soil structure and fertility while contributing to climate mitigation. Thus, improving soil fertility within CSA frameworks is vital for building resilient agricultural systems that sustain food security and climate goals.

Technologies and Innovations to Enhance Soil Fertility

Advances in technologies and innovations play a crucial role in enhancing soil fertility and promoting sustainable, climate-smart agriculture. Soil testing and nutrient management tools, such as the Soil Health Card scheme launched in India, provide farmers with detailed information on soil nutrient status, helping optimize fertilizer use and reduce environmental impacts (Department of Agriculture, Cooperation & Farmers Welfare, 2020). Studies show that targeted nutrient management through soil testing can improve crop yields by up to 15-20% while lowering fertilizer costs (Srinivasarao et al., 2019).

Precision agriculture, enabled by GPS, remote sensing, and digital soil mapping, allows site-specific nutrient application, minimizing wastage and maximizing nutrient use efficiency. Globally, precision farming technologies have reduced fertilizer input by 10-30%, contributing to lower greenhouse gas emissions and improved soil health (Zhang et al., 2019). Biofertilizers, comprising beneficial microorganisms such as nitrogen-fixing bacteria and phosphate-solubilizing fungi, enhance nutrient availability naturally and sustainably. Integrated nutrient management (INM) combining chemical fertilizers, organic amendments, and biofertilizers sustains soil fertility and supports climate resilience by improving soil organic carbon and microbial diversity.

These innovative approaches are vital to meet the challenges posed by climate change and environmental degradation, ensuring productive and resilient agricultural systems for the future.

Conclusion

Soil fertility is the cornerstone of sustainable and climate-smart agriculture, influencing crop productivity, environmental health, and resilience to climate change. Maintaining balanced soil nutrient status, promoting organic matter, and adopting innovative technologies are vital to safeguard soil health. Integrated approaches combining policy support, farmer empowerment, and cutting-edge research are imperative to overcome challenges and ensure food security in a changing climate. By prioritizing soil fertility, we can pave the way toward more productive, sustainable, and climate-resilient agricultural landscapes.

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Agroforestry and Shelterbelt Interventions for Enhancing Soil Health and Crop Productivity in the Indian Thar Desert

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Introduction

Desertification is a serious environmental challenge in arid and semi-arid regions characterized by the degradation of land, loss of soil fertility, and reduction in biological productivity due to climatic variations and anthropogenic activities. The fragile ecosystems of these drylands are highly susceptible to erosion, moisture depletion, and vegetation loss, which exacerbate the cycle of land degradation. To combat desertification, sustainable land management approaches are critical, among which agroforestry and shelterbelts have emerged as promising nature-based solutions. Agroforestry integrates trees and shrubs into agricultural landscapes, while shelterbelts are linear plantings of trees or shrubs designed to protect crops and soil from wind and erosion. Both systems contribute significantly to restoring ecosystem functions, enhancing microclimates, and conserving soil resources in arid regions.

2. Desertification in Arid Regions: Causes and Consequences

Desertification refers to the process by which fertile land degrades into desert-like conditions, primarily due to natural factors and human activities. This phenomenon severely affects arid and semi-arid regions, leading to land degradation, loss of productivity, and ecological imbalance. Desertification in arid regions arises from both climatic and human-induced factors. Low and erratic rainfall, coupled with high temperatures and prolonged droughts, leads to moisture stress and sparse vegetation, making soils more vulnerable. Wind and water erosion become severe due to exposed soil surfaces, with wind carrying away fine particles and intense rain causing runoff that strips the topsoil. Overgrazing by livestock removes protective vegetation cover and compacts the soil, reducing its ability to absorb water and support plant growth. Unsustainable farming practices like continuous monocropping, lack of cover crops, and improper irrigation (leading to salinity and waterlogging) further degrade soil health. Additionally, deforestation removes trees that stabilize soil and regulate microclimates, thereby accelerating erosion and moisture loss. These interacting factors collectively drive the progression of desertification in arid landscapes.

2.2 Consequences

Reduced soil organic matter and fertility

- ✓ Organic matter, derived from decomposed plant and animal residues, is essential for soil structure, nutrient retention, and microbial activity.
- ✓ Desertification processes accelerate the loss of organic matter, reducing soil fertility and its ability to support crops and natural vegetation.

Decline in water retention capacity

- ✓ Soil degradation and compaction reduce pore space, limiting the soil's ability to absorb and hold water.
- ✓ Reduced vegetation cover means less shade and ground cover, leading to higher evaporation rates and less moisture retention in the soil profile.
- ✓ These factors cause drought-like conditions even with occasional rainfall, stressing plants and reducing productivity.

Loss of biodiversity and vegetation cover

- ✓ As land degrades, native plants and animal species decline due to habitat loss and harsh conditions.
- ✓ This biodiversity loss destabilizes ecosystems, reduces resilience against pests and diseases, and diminishes ecological services such as pollination and nutrient cycling.

Increased frequency of dust storms and sand encroachment

- ✓ Exposed loose soil particles become airborne during strong winds, causing dust storms that degrade air quality and harm human and animal health.
- ✓ Sand encroachment can bury croplands and settlements, making them unproductive and uninhabitable.

Negative impact on rural livelihoods and food security

- ✓ Decreased soil fertility and water availability lead to reduced crop yields and fodder production.
- ✓ Livestock productivity declines due to poor forage availability and harsh climatic conditions.
- ✓ These effects threaten the income and food security of rural populations dependent on agriculture and pastoralism, leading to poverty and migration pressures.

3. Agroforestry: Concept and Types Relevant to Arid Zones

3.1 What is Agroforestry?

Agroforestry is the deliberate integration of woody perennials (trees, shrubs) with crops and/or livestock on the same land management unit, generating ecological and economic benefits.

3.2 Types of Agroforestry Systems Suitable for Arid Regions

- Alley Cropping: Trees planted in rows with crops grown in alleys between them, improving soil and microclimate
- Silvopastoral Systems: Integration of trees with pasture and livestock, enhancing fodder availability and shade
- Windbreaks and Shelterbelts: Trees or shrubs planted as barriers to reduce wind speed and protect soils
- Boundary Plantations: Trees/shrubs planted along field boundaries to reduce soil erosion and demarcate land

3.3 Common Multipurpose Trees and Shrubs Used

Multipurpose tree species (MPTS) are ecological engineers in arid landscapes. Their deep roots, nutrient-rich biomass, and functional biodiversity

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contribute immensely to land restoration, climate resilience, and sustainable farming systems. Promoting MPTS through agroforestry and silvopastoral systems not only improves soil health and productivity but also strengthens the socioeconomic stability of communities in vulnerable dryland ecosystems.

Species	**Nutrient Content (Dry Matter Basis)**	**Soil Health Functions**
Prosopis cineraria (Khejri)	CP: 12–15%, Ca: 2.3%, P: 0.3%	Nitrogen fixation, high organic matter contribution, improves microbial biomass, deep taproot breaks hardpan
Calligonum polygonoides (Phog)	CP: 9–12%, high ash, P-rich	Stabilizes sand dunes, improves soil porosity, supports soil arthropods and mycorrhizae
Acacia senegal *(Gum Arabic tree)*	CP: 13–17%, high in gum polysaccharides	Nitrogen fixer, improves soil aggregation, enhances rhizospheric microbial activity through gum exudates
Tamarix spp.	CP: 8–10%, salt-tolerant, low P	Controls saline soil encroachment, traps windblown sediments, tolerates high EC and sodicity
Leucaena leucocephala	CP: 20–28%, Ca: 2.0%, P: 0.25%, high digestibility	Fast-growing nitrogen fixer, high leaf biomass adds nutrients, improves C:N ratio, enhances mycorrhizal colonization
Ziziphus mauritiana (Ber)	CP: 10–12% (leaves), Fruit rich in Vitamin C	Enhances organic matter through fruit/leaf fall, roots improve structure, supports microbial biomass
Moringa oleifera	CP: 25–30% (leaves), rich in micronutrients (Fe, Zn, Se)	Boosts soil fertility via rapid biomass turnover, improves micronutrient availability in rhizosphere

4. Role of Agroforestry and Shelterbelts in Mitigating Desertification

4.1 Soil Conservation

- **Reduction of wind erosion:** Shelterbelts act as physical barriers that reduce wind velocity by up to 50-70%, lowering the potential for wind-blown soil loss. The aerodynamic effect creates a zone of calm air behind the shelterbelt where soil particles are less disturbed.
- **Water erosion control:** Tree roots stabilize soil aggregates, increasing resistance to water erosion. Their leaf litter improves organic matter content, promoting soil aggregation and infiltration.

Soil fertility enhancement: Multipurpose trees fix atmospheric nitrogen (in legumes like *Prosopis* and *Leucaena*), add organic matter via litterfall and root biomass, and enhance microbial activity, all of which improve soil nutrient status.

4.2 Microclimate Improvement

- **Temperature moderation:** Tree canopies provide shade, reducing soil and air temperatures, which helps conserve soil moisture and protects crops from heat stress.

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- **Humidity increase:** Transpiration from trees increases relative humidity in the immediate vicinity, reducing evapotranspiration rates in crops and soils.
- **Wind speed reduction:** Shelterbelts lower wind velocity, which decreases evapotranspiration and moisture loss from soil and plants. This windbreak effect protects young seedlings and delicate crops from wind damage.

4.3 Biodiversity and Habitat Conservation

Agroforestry systems create habitats for beneficial insects, birds, and microorganisms that support natural pest control and pollination, contributing to ecosystem stability. They also preserve native flora and fauna, reducing desertification-related biodiversity loss.

4.4 Carbon Sequestration and Climate Change Mitigation

Trees in agroforestry systems sequester significant amounts of carbon in biomass and soil, reducing greenhouse gas concentrations and helping mitigate climate change impacts that exacerbate desertification.

5. Socioeconomic Benefits and Livelihood Support

- Diversification of farm income: Sale of fruits, fodder, timber, and fuelwood from multipurpose trees supplements farmer income.
- Improved livestock productivity: Shade and fodder availability improve animal health and milk/meat yield.
- Sustainable resource use: Reduced need for chemical fertilizers through nitrogen fixation and organic matter addition lowers input costs.
- Food security and resilience: Improved soil moisture and fertility contribute to higher and more stable crop yields under drought conditions.

6. Agroforestry and shelterbelt systems

Agroforestry and shelterbelt systems have been successfully implemented and studied in the arid regions of India, particularly in the Thar Desert of Rajasthan. These approaches have demonstrated significant potential to mitigate land degradation, enhance soil fertility, and improve crop productivity under moisture-stressed conditions.

6.1 Agroforestry in the Thar Desert, India

- The Thar Desert faces harsh climatic conditions and poor soil fertility, limiting crop productivity.
- Integration of *Prosopis cineraria* (Khejri) into traditional cropping systems has shown significant benefits.
- 20–30% increase in soil organic carbon, attributed to leaf litter input and deep root biomass.
- Enhanced microbial activity in the rhizosphere, improving nutrient cycling and soil health.
- *P. cineraria* agroforestry systems significantly reduce wind erosion by up to 60%:
- Tree canopy slows wind speed and traps loose soil particles.
- Soil becomes more stable, reducing land degradation.
- Improved microclimatic and edaphic conditions under Khejri trees lead to 15–25% increase in crop yields compared to sole cropping and positive effects observed in

crops like pearl millet, moth bean, and cluster bean.

- These results validate traditional agroforestry with Khejri as a sustainable and climate-resilient land-use system in arid regions.

6.2 Shelterbelt Success in Rajasthan

- Shelterbelts involve linear plantations of trees or shrubs around agricultural fields to protect against wind erosion.
- In Rajasthan, commonly used species include: *Acacia tortilis*, *Acacia senegal*, and *Tamarix aphylla*, all drought- and salt-tolerant.
- Long-term research and field trials have documented key benefits: Wind speed reduction by 40–60%, effective up to 10–15 times the tree height. Lowered wind erosion, especially during high wind periods in summer and early monsoon.
- Shelterbelt-protected fields show 12–18% higher soil moisture retention, crucial for arid zone agriculture. Improved seed germination and early seedling growth, reducing crop failure risks.
- 10–20% higher yields observed in crops like pearl millet, mung bean, and cowpea and better crop establishment due to moderated microclimate and reduced soil loss.

7. Challenges and Recommendations

7.1 Challenges

- **Limited awareness and extension outreach**: Many farmers lack awareness of the long-term ecological and economic benefits of agroforestry and shelterbelt systems in arid regions.
- **High initial establishment costs**: Expenses related to fencing, planting materials, labor, and irrigation during the early years deter adoption, especially among smallholder farmers.
- **Slow return on investment**: Tree components in agroforestry systems take time to mature and provide economic returns, which discourages farmers seeking immediate benefits.
- **Water and nutrient competition**: In hyper-arid zones, trees may compete with annual crops for limited soil moisture and nutrients, particularly during early crop growth stages.
- **Inadequate research on species-site matching**: A lack of region-specific data on suitable tree-crop combinations, root dynamics, and agroforestry design hinders optimal system planning.
- **Policy and institutional gaps**: Weak integration of agroforestry within existing land management, climate adaptation, and rural development programs limits large-scale adoption.
- **Grazing pressure and lack of protection**: Uncontrolled grazing, particularly during the establishment phase, severely affects tree survival and success of shelterbelts.

7.2 Recommendations

- **Enhance awareness and capacity building**: Promote farmer training programs, participatory demonstrations, and community-level workshops to showcase successful agroforestry models.
- **Provide financial and material support**: Offer subsidies or incentives for initial investments (fencing, planting materials), and explore linkages with carbon credits and tree-based value chains.
- **Promote water-smart agroforestry designs**: Encourage use of drought-tolerant species, root pruning, and appropriate spacing to minimize tree-crop competition for water.
- **Strengthen site-specific research**: Invest in long-term agroforestry trials to evaluate productivity, carbon sequestration, hydrological impacts, and soil health under different configurations.
- **Facilitate access to quality planting material**: Establish decentralized nurseries

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- and seed banks to supply genetically superior and locally adapted MPTS seedlings.
- **Integrate agroforestry into rural development schemes**: Mainstream agroforestry into government programs such as MGNREGA, PMKSY, and watershed missions for convergence and scale.
- **Promote community-based models**: Encourage participatory management of shelterbelts and agroforestry plantations on common lands to improve social equity and resource sharing.

8. Conclusion

Agroforestry and shelterbelts are effective, ecologically sustainable strategies to combat desertification in arid regions. By improving soil health, enhancing microclimate conditions, and supporting biodiversity, these systems contribute to the restoration of degraded lands, increase agricultural productivity, and bolster farmer livelihoods. For long-term success, integration of local knowledge with scientific research and supportive policies is essential.

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Importance of Golden Shower (Cassia fistula) Tree in Monsoon Forecasting: A Review

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There is a popular belief: "If the Amaltas tree blooms profusely, the rainfall will be good and timely". Its flowering occurs from April to June, just before the monsoon arrives, allowing people to estimate the upcoming rainfall intensity. Amaltas is a key species in the traditional knowledge system, helping communities anticipate climatic changes. Weather forecasts enable precise planning, cost control, and risk management in sectors like agriculture, industry, transportation, energy, insurance, and disaster management. Forecasts help farmers in various farm decisions like sowing, irrigation, pest and disease management, harvesting, etc. As Amaltas tree indicates arrival of monsoon, it is important tree to the farming community in this regard. Many researchers have proved this fact and it was also reflected in traditional knowledge system of India.

Introduction

Golden Shower (*Cassia fistula*) tree

Golden Shower (*Cassia fistula*) tree is known by various names in different languages: in Sanskrit as Vyadighata, Nripadruma, Aragvadh, Karnikara; in Marathi as Bahava, Karnikara; in Gujarati as Garamastho; in Bengali as Sonalu; and in Latin as *Cassia fistula*. According to the Shabdasagar, the Hindi word Amaltas derives from the Sanskrit word *Amla* meaning sour (Sharma, 1998; Jain, 2004).The tree is found throughout almost all regions of India. Its trunk circumference ranges from three to five feet, though the tree itself is not very tall. During the sunny months of April and May, the entire tree becomes covered with long clusters of yellow flowers. It is believed that rain arrives approximately 45 days after the flowers bloom. Because of this, it is also called the Golden Shower Tree and the Indian Rain Indicator Tree (Parrotta, 2001; Jain and Srivastava, 2010). In winter, the tree bears black, cylindrical pods about one and a quarter hand-length long. These pods contain multiple chambers filled with black, sticky pulp. The branches, when peeled, exude a reddish sap that hardens like gum. The pods yield a fragrant, yellowish volatile oil (Singh *et al*., 2007).

In the subtropical plains of northern India, Cassia fistula—commonly known as Amaltas or Golden Shower Tree—dominates the skies during summer from mid-May to mid-June and beyond. It belongs to the family Caesalpiniaceae and is revered in Ayurveda as the "Royal Tree" (Rajvriksha) (Kumar and Singh, 2015). It is deciduous, shedding its leaves as it blooms in long, grape-like clusters of golden flowers, making it one of the most attractive tropical trees. Originating from Southeast Asia, it is now found naturally in many tropical regions, including Ecuador, West Indies, Belize, Mexico, and parts of Micronesia, and has been introduced in places like Queensland, Australia. Due to its many beneficial properties, it is widely cultivated in India. The tree can grow up to 30–40 feet tall and wide. Its growth rate is influenced by soil type, sunlight, temperature, and other environmental conditions. It is often grown as an ornamental tree in parks, public spaces, and institutional settings (Morton, 1987; Singh and Singh, 2013).

Key Characteristics of Cassia Fistula

- **Flower Color:** Bright Yellow (Golden Yellow)
- **Flowering Period:** Summer, especially May to June
- **Flower Structure:** Long, hanging clusters resembling bunches of grapes
- **Leaves:** The tree sheds its leaves while flowering in summer
- **Size:** Approximately 30–40 feet in height and width

These botanical characteristics are well documented in floras and ethnobotanical surveys (Chopra *et al*., 1956; Gamble, 1915).

***Cassia Fistula* as a Monsoon Indicator:**

In many parts of India, there is a popular belief: “If the Amaltas tree blooms profusely, the rainfall will be good and timely” (Ramakrishna *et al*., 2017). Its flowering occurs from April to June, just before the monsoon arrives, allowing people to estimate the upcoming rainfall intensity (Rajagopal and Jayaprakash, 2012).The flowering is linked to several natural factors such as soil moisture, rising temperature, and atmospheric humidity all of which are favorable conditions for the monsoon (Kumar et al., 2010; Singh and Gupta, 2015).

Ethno-Meteorology and Traditional Weather Knowledge:

Ethno-meteorology studies traditional weather knowledge among rural and tribal communities (Roy, 2013). Farmers, shepherds, and forest dwellers predict the weather by observing the behavior of trees, birds, and insects (Behera *et al*., 2018). Amaltas is a key species in this traditional knowledge system, helping communities anticipate climatic changes (Choudhury & Bhattacharyya, 2016).

Importance of Weather Forecasting in Agriculture:

Weather forecasting is not just a means to provide information about temperature or rainfall but is a strategic tool that plays a crucial role in strengthening the economic framework of a country. Its accurate and timely use benefits farmers, traders, investors, and common people economically and significantly reduces financial risks (Katz and Brown, 1992; Wilhite, 2000).

Weather forecasts enable precise planning, cost control, and risk management in sectors like agriculture, industry, transportation, energy, insurance, and disaster management. Thus, weather forecasting has become a strategic economic instrument that helps any nation protect itself from climate change and natural disasters while promoting sustainable development (Lazo *et al*., 2009; IPCC, 2014). Moreover, the importance of weather forecasting is not limited to daily life—it is also extremely useful in critical areas such as defense, health, industrial production, and environmental conservation (Glahn & Ruth, 2003). It enables better planning, ensures safety, and helps avoid natural calamities. Therefore, in the modern era, weather forecasting has become an indispensable resource that improves the quality of life, maintains economic stability, and sustains environmental balance (National Research Council, 2006).

- **Correct Timing of Sowing and Harvesting:** Farmers use weather forecasts to determine the best time to sow and harvest crops based on expected rainfall or drought (Kumar and Katiyar, 2014).
- **Better Irrigation Management:** Forecasts help farmers save water by reducing unnecessary irrigation before rainfall and planning irrigation during dry spells (Sharma *et al*., 2015).
- **Pest and Disease Control:** Changes in humidity and temperature can increase pest and disease outbreaks; forecasts allow farmers to take preventive measures (Pathak et al., 2012).
- **Disaster Management:** Early warnings enable farmers to protect crops and property from floods, storms, and other disasters (Narayan *et al*., 2011).
- **Food Security:** Accurate forecasts help maintain crop production and quality, preventing food shortages (FAO, 2013).
- **Agribusiness Benefits:** Weather forecasts aid planning in allied sectors like dairy, horticulture, and agro-input businesses (Singh and Singh, 2017).
- **Climate Change Adaptation:** Forecasts assist farmers in adapting to climate variability by adopting suitable crops and technologies (IPCC, 2014).

Cassia Fistula as a temperature Indicator:

Cassia Fistula flowers when the ambient temperature rises sharply, especially during mid-summer (April to June) (Karthikeyan *et al*., 2014). It sheds leaves and focuses energy on flowering when temperatures peak, signaling the height of summer. Rural communities interpret its flowering as an indicator of rising temperature and changing weather conditions (Dutta *et al*., 2018). Scientifically, its flowering is linked to temperatures between 30–40°C and is a phenological response to climatic factors (Prasad and Singh, 2017). It supports local climate knowledge and assists agricultural decision-making (Chaudhary and Rana, 2019).

Cassia fistula and Atmospheric Humidity:

Cassia fistula is highly sensitive to changes in atmospheric humidity, particularly in the pre-monsoon season (Ramesh and Nair, 2011). As humidity rises from April to June, the tree bursts into bright yellow blooms. Flowering correlates with increased temperature, rising humidity, and stable atmospheric conditions, signaling monsoon onset (Venkatesh and Ramachandra, 2013). Traditional beliefs hold that flowering indicates an increase in humidity and impending rainfall (Sundararajan, 2014). Scientific studies show that Cassia fistula flowers more vigorously when humidity exceeds 40–50%, with warm and moist conditions facilitating flower development (Singh et al., 2016). The tree acts as a biological sensor for transitioning from dry to humid monsoon conditions, serving as a phenological indicator of seasonal and climate changes (Gupta and Kumar, 2018).

Cassia fistula and Atmospheric Wind:

The tree is somewhat sensitive to wind and environmental conditions, but the direct effects of wind on flowering are not very prominent. Wind can cause flowers and leaves to fall prematurely, especially strong or cold winds before the monsoon (Patel and Joshi, 2010). Traditional knowledge associates the arrival of cold winds with the approach of the monsoon season (Chatterjee, 2009). Scientific observations note that strong winds can accelerate flower and leaf drop, signaling environmental changes (Bhat and Sharma, 2011).

Conclusion:

Cassia fistula plays a vital role in traditional ethno-meteorology and is considered a natural weather indicator in rural India. It is a natural temperature indicator tree, responding biologically to rising temperatures and marking the peak of summer. Its flowering is a key component of traditional climate knowledge and scientific phenology. While its direct

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relation to wind is less clear, the tree responds to changes in wind patterns by shedding flowers and leaves. *Cassia Fistula* s acts as a biological sensor for increasing humidity and the onset of the monsoon, making it an important traditional and environmental indicator along with its medicinal and ornamental value, Amaltas is an essential part of the natural monsoon forecasting system, reflecting subtle environmental changes that precede rainfall. Therefore, it is regarded as a "natural weather scientist" in rural India.

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From pollution to solution: How biochar helps to heal the Earth

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India generates a staggering volume of agricultural waste, with an estimated 141 million tonnes (MT) of crop residues produced annually. Unfortunately, about 92 MT of this biomass is openly burned in fields due to the absence of efficient and sustainable waste management systems (Gatkal *et al*., 2024). This widespread practice of stubble burning significantly worsens air quality by releasing large amounts of particulate matter (PM2.5 and PM10) and greenhouse gases into the atmosphere. The result is a sharp rise in respiratory diseases, premature deaths, and climate-related impacts. Moreover, repeated burning depletes vital soil nutrients, disrupts the microbial ecosystem, and threatens long-term agro-environmental stability.

However, this crop waste rich in organic carbon and essential nutrients represents an untapped resource. When properly managed, it can be converted into valuable products such as compost, bioenergy, or biochar. Among these, biochar production has emerged as one of the most promising and sustainable waste management strategies. Biochar is a carbon-rich, porous material produced by heating organic biomass (like crop residues) at high temperatures under low or no oxygen conditions, a process known as pyrolysis (Hossain *et al.,* 2020). Unlike open burning, this method locks carbon into a stable form, preventing its release into the atmosphere and instead returning it to the soil.

Biochar production methodologies

Biochar can be produced using various methods based on the type of biomass, scale of production, and available resources, whether on farms or in dedicated facilities. Though its use dates back to ancient times, biochar has recently gained attention for its potential in climate change mitigation. Artificial production through pyrolysis has become common to harness its benefits. For instance, Wang *et al*. (2013) developed a continuous bioenergy pyrolysis system using crop residues.

Biochar can also be made in traditional earthen kilns, where pyrolysis, gasification, and combustion occur simultaneously, or in modern biochar retorts. In slow pyrolysis, biomass is heated gradually in low-oxygen conditions, while fast pyrolysis involves rapid heating of fine particles at temperatures below 650 °C. Factors like heating rate, particle size, and residence time significantly influence the quality and characteristics of the resulting biochar (Nartey and Zhao, 2014).

Characteristics of Biochar

Biochar varies depending on the type of biomass and production method used. This includes analyzing its physical, chemical, and structural traits to assess its quality and suitability. Biochar is known for its porous structure and large surface area, which help retain water and nutrients in the soil (Liu *et al.,* 2022). It is usually alkaline and contains beneficial minerals like potassium, calcium, and magnesium. Its stable carbon structure allows it to remain in the soil for hundreds of years, helping store carbon and reducing greenhouse gas emissions.

The role of biochar in climate-friendly agriculture

Biochar offers an innovative and eco-friendly solution for managing agricultural crop residues while simultaneously addressing pollution and climate change. In many farming regions, vast amounts of crop residues are burned in open fields, releasing toxic smoke, fine particulate matter, and greenhouse gases into the atmosphere. This not only harms human health and degrades air quality but also accelerates global warming and leads to the loss of essential soil nutrients (Gatmal *et at*., 2024). Converting these residues into biochar through controlled pyrolysis transforms a pollution source into a valuable resource. Instead of being released as harmful emissions, the carbon in biomass is locked into a stable form and returned to the soil. Biochar not only prevents air pollution but also enriches soil fertility, boosts water retention, and enhances nutrient use efficiency, promoting healthier and more resilient crops (Hu *et al.*, 2023). Moreover, by sequestering carbon in the soil for hundreds of years, biochar acts as a powerful tool in the fight against climate change. Thus, integrating biochar into crop residue management not only mitigates environmental damage but also paves the way for sustainable and climate-smart agriculture.

Effect of biochar on soil health: A tool to heal the Earth

Biochar greatly improves soil health, making it ideal for restoring degraded land and supporting sustainable farming. Its porous structure enhances water retention, aeration, and root growth, especially in poor or compacted soils. It holds essential nutrients like nitrogen, phosphorus, and potassium, reducing losses and improving plant uptake.

Biochar also boosts soil biology by providing a habitat for beneficial microbes, such as nitrogen-fixing bacteria and mycorrhizal fungi, which are vital for nutrient cycling and plant health (Purakayasta *et al*., 2015). It helps balance soil pH, especially in acidic soils, creating better conditions for crops.

Importantly, biochar sequesters carbon in the soil for centuries, cutting greenhouse gas emissions and aiding in climate change mitigation. By improving soil fertility, water use, and carbon storage, biochar helps heal the Earth and transform damaged soils into healthy, productive ecosystems.

Conclusion

Biochar gives us a practical and meaningful way to tackle some of the biggest problems in farming and the environment. Instead of burning crop residues and polluting the air, we can turn that waste into something useful biochar. It not only helps clean the air but also improves soil, boosts crop growth, and locks away carbon for years, helping us fight climate change. If more people become aware of its benefits and get access to the right tools and support, biochar could turn what was once a harmful practice into a solution that supports both the Earth and the farmer. It's a small change with the power to make a big difference.

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Beekeeping: An Extra Revenue Stream for Farmers

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Diversification in agriculture is a subsistence farming practice in which farmers grow a variety of crops on a plot of land and run multiple businesses as part of their farm portfolio. Agricultural diversification was primarily concerned with household food and financial stability. Agricultural diversification has gained popularity in recent decades and is thought to be the solution to all of the nation's agricultural development's issues. Diversification is meant to boost the nation's level of self-sufficiency at the national level. Diversification is being encouraged at the regional level to lessen the adverse externalities connected to monocropping. Indian farmers might choose to diversify their crops by raising pigs, dairy products, poultry, and bees. Beekeeping is one of these possibilities that farmers may easily manage on their farms. Beekeeping yielded high-value products like honey and wax, but it required less initial investment. Beekeeping is a decentralised sector dependent on agriculture and forests. It operates as a commercial, complementary, single-family, or pollution-free subsidiary business. The process of raising and caring for honey bees, or beekeeping, greatly benefits human wellbeing and the economy. This modest cottage industry relies on planned bee management technology to succeed. In addition to producing valuable goods from a medicinal and commercial standpoint, such as honey, beeswax, royal jelly, propolis, and bee venom, honeybees are also essential for pollinating a variety of fruits and crops. In his constructive program to maximise self-employment via innovation and human dignity, Mahatma Gandhi also advocated beekeeping as a business.

Economic Importance of Apiculture

Provides Honey: Honey bees make honey, which is a viscous, light brown liquid. Fructose (38.5%), glucose (31%), sucrose (1.3%), and maltose (7.1%) are among the sugars that make up honey. Honey bees use their gloss and proboscis to extract nectar from flowers, which they then collect in a comb to make honey. During the sucking process, saliva is

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also introduced to the nectar at a little percentage. This gathered substance, referred to as raw honey, is put into the honey chambers and subsequently dried with the aid of wings to turn it into honey. Honey is a nutrient-dense food with therapeutic benefits.

Provide Wax: The worker honey bees secrete it. Worker honey bees have wax glands on the ventral side of their abdomens that create wax. This dries up and builds up above the hive, creating the hive's walls. Human life benefits from honey wax. Cream, lipsticks, polish, beauty creams, carbon paper, and other models are made from this.

Bee Propolis - Bee Propolis is not predominantly secreted from the body of the bee. Propolis is a resinous compound of waxy consistency that worker honey bees manufacture by mixing saliva and bee wax with exudates obtained from tree buds, sap flows, and other botanical sources and water. It is applied to the hive's exposed areas as a sealant. While beeswax is typically used to fill bigger voids, bee propolis is used for smaller gaps. At 20°C and higher, it is sticky; at lower temperatures, it hardens. Bee propolis is mostly useful as a cold remedy. It improves women's fertility and gynaecological care.

Bee Venom -The acid glands of worker bees secrete a colourless, acidic liquid known as bee venom. The bee secretes it through a string when she senses danger. It contains minerals, sugar, amino acids, enzymes, and other inflammatory substances. The most costly product made by bees is bee venom. The best source of revenue may be bee venom. Joint discomfort can be treated with bee venom.

Government schemes for Beekeeping

The Indian government has implemented many programs to encourage beekeeping after realising its potential. Here are a few well-known beekeeping programs in India.

Supporting Pollination with Beekeeping

Under the Mission for Integrated Horticulture (MIDH) scheme, the Government of India supports beekeeping for pollination support to horticultural crops. Honeybees can be used as an important input to maximise agricultural production. The National Bee Board (NBB) will be responsible for coordinating beekeeping activity in states, and assistance will be available for activities related to bee breeding, bee nucleus stock development, bee distribution, and beekeeping equipment.

Sweet Kranti

Following a clarion cry by the Hon. Prime Minister, "SWEET KRANTI," KVIC began the Honey Mission. India's government started the Sweet Kranti plan, sometimes called the Honey Mission, in 2017 through the Khadi and Village Industries Commission (KVIC). Throughout the nation, it seeks to encourage apiculture, or beekeeping.

Increased Honey Production: The program intends to greatly increase India's production of honey, increasing its accessibility and maybe turning it into an export good.

Rural Development and Livelihood Generation: The goal of Sweet Kranti is to empower people by giving them the tools and training to begin beekeeping businesses, especially Adivasis (indigenous communities), farmers, young people without jobs, and women. This can support rural economic development and serve as an additional source of income.

Improved Crop Yield: The pollination process, which helps boost the output of many crops, depends heavily on honeybees. The Sweet Kranti initiative indirectly boosts agricultural output by promoting beekeeping.

Benefits

Financial Assistance: The program provides subsidised bee boxes, beekeeping supplies, and training courses to beekeepers as financial aid.

Training and Support: KVIC offers thorough instruction to beekeepers on managing hives, extracting honey, and other crucial beekeeping procedures.

Processing and Marketing Support: The program ensures beekeepers receive fair pricing for their

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honey by connecting them with marketing channels and processing facilities.

Mobile Processing Units: Mobile honey processing vans that visit beekeepers directly are a recent innovation under Sweet Kranti that streamlines the processing process and lowers transportation costs.

Conclusion

A sustainable and profitable way to improve rural livelihoods and the productivity of the country's agriculture is through agricultural diversification, especially through apiculture. Beekeeping greatly increases crop pollination, which raises yields, in addition to producing high-value goods like honey, wax, propolis, and bee venom. Due to its low investment requirements, small and marginal farmers may afford it. Important assistance is provided by government programs like MIDH and Sweet Kranti, which provide market access, financial help, and training. Through ethical and fruitful farming methods, beekeeping can help India become more self-sufficient, strengthen rural communities, and maintain ecological equilibrium.

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Empowering India: A Holistic Approach to Promoting Self-Employment During the Amrit Kaal

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This comprehensive review explores strategic initiatives aimed at promoting self-employment in India during the transformative period of the Amrit Kaal. Addressing challenges such as limited access to capital, inadequate skills, constrained market reach, and gender disparities, the study proposes multifaceted solutions. These solutions encompass financial inclusion through microfinance programs, targeted skill development initiatives facilitated by educational institutions and online platforms, digital transformation support enabling businesses to expand their online presence, and gender-inclusive entrepreneurship programs tailored to empower women entrepreneurs. The feasibility of these solutions is underscored by their integration into existing infrastructures, making them economically viable. Moreover, these initiatives align with environmental sustainability goals, promoting eco-friendly entrepreneurship and renewable practices. The scalability of these strategies is ensured through collaborative efforts between governmental bodies, non-governmental organizations, and private sectors, allowing for widespread implementation across diverse regions. This research emphasizes the economic viability of empowering individuals through self-employment, creating a positive ripple effect on the local economy.

Introduction:

India's socio-economic environment has seen a significant change during the Amrit Kaal, a time of tremendous challenges and transitions. The encouragement of self-employment has become a powerful motivator for social and economic advancement in this period of transition. The Amrit Kaal not only demonstrated the people of India's tenacity but also called for creative solutions to complex problems. The key to overcoming these obstacles is to address the continuing gender gaps in entrepreneurship, the difficulty of expanding market reach, the lack of necessary skills, and the restricted access to financing.

Limited Access to Capital: One of the significant hurdles faced by aspiring entrepreneurs was the

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scarcity of financial resources. Without access to capital, even the most ingenious business ideas remained confined to the realms of imagination. Recognizing this challenge, policymakers and financial institutions took bold strides to bridge the gap between aspirations and actualization. Microfinance programs emerged as a beacon of hope, providing tailored financial solutions to individuals with entrepreneurial dreams. These initiatives, infused with the spirit of inclusivity, became instrumental in turning dreams into viable business ventures.

Lack of Skills and Training: In the dynamic landscape of Amrit Kaal, traditional skills often proved inadequate in meeting the demands of evolving markets. There arose a pressing need for comprehensive skill development initiatives to empower individuals with the ability to shape their destinies. Educational institutions and online platforms became the battlegrounds for nurturing talent and imparting practical know-how. Through a plethora of workshops, seminars, and online courses, individuals acquired skills ranging from digital marketing to sustainable business practices, enabling them to navigate the competitive entrepreneurial sphere.

Limited Market Reach: The digital revolution, a defining characteristic of Amrit Kaal, opened doors to unprecedented opportunities. However, many small businesses struggled to harness the potential of the digital domain. The solution lies in providing unwavering support to businesses in their digital transformation journey. Workshops and consultations became invaluable resources, guiding entrepreneurs in leveraging e-commerce platforms, digital marketing strategies, and secure online payment gateways. These interventions not only expanded market reach but also equipped businesses with the tools to thrive in the digital age.

Gender Disparities: In the tapestry of entrepreneurship, women's contributions have often been overshadowed by societal norms and limited access to resources. The Amrit Kaal demanded a paradigm shift, recognizing the immense potential of women entrepreneurs. Tailored initiatives and mentorship programs emerged, specifically designed to address the unique challenges faced by women. By fostering a supportive ecosystem and providing access to capital and mentorship, these programs empowered women to break the shackles of gender disparity and emerge as trailblazers in the entrepreneurial landscape.

The viability of these projects was shown to be a crucial factor in assessing their effectiveness. When these solutions were incorporated into already-existing infrastructures, they became not only practical but also long-term sustainable. Financial inclusion initiatives guaranteed the smooth flow of money to prospective entrepreneurs when they were coordinated with microfinance institutions and banking networks. Similar to this, skill development initiatives showed promise for broad scalability, reaching people in even the most remote regions of the nation—whether they were run through internet platforms or conventional educational institutions. Furthermore, these programs' financial sustainability was demonstrated by the way they boosted the regional and national economies. Equipped with the necessary capital and expertise, empowered entrepreneurs set off on a path of success that led to the creation of jobs, more consumer spending, and ultimately enhanced economic growth. Furthermore, these techniques' emphasis on environmental sustainability promoted an eco-conscious entrepreneurial culture. These programs supported economic growth and helped preserve the environment by supporting green practices, renewable energy sources, and ecologically friendly industrial techniques. The emphasis on self-employment is a testament to India's dedication to equality, economic prosperity, and environmental care as the country navigates the transforming currents of the Amrit Kaal. India has established a thriving entrepreneurial ecosystem by tackling the fundamental issues of restricted access to money, skills, market reach, and gender imbalances. This

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thorough analysis explores the core of these projects, looking at their effects, viability from an economic standpoint, environmental sustainability, and scalability. This study illuminates the extraordinary process of enabling people to write their own success stories and so create a more hopeful and inclusive future for the country by carefully examining these variables.

Proposed Solutions: Empowering India's Self-Employment Revolution

The challenges faced during the Amrit Kaal spurred India into action, leading to innovative solutions to promote self-employment across diverse sectors. Data and statistics from various sources underscore the effectiveness of these initiatives, painting a vibrant picture of India's evolving entrepreneurial landscape.

1. Financial Inclusion and Microfinance Programs:

Access to finance is the lifeblood of entrepreneurship. Microfinance programs, championed by institutions like the Micro Units Development and Refinance Agency (MUDRA), have played a pivotal role. Since their inception, these programs have disbursed millions of loans to small businesses and entrepreneurs. As of 2022, MUDRA has sanctioned under the PMMY scheme a total amount of 3.39 lakh crore in 5.37 crore loan accounts, which has helped in extending the much-needed financial support to the informal and micro enterprises, mostly promoted by the weaker sections of the society, viz., SC/ST/OBC/Women entrepreneurs. The Banks, NBFCs and MFIs which have catered to the informal sector, micro-enterprise & small business segment under PMMY, have proven themselves as champions in sustaining the livelihoods and enterprises at the bottom of the pyramid [1]

2. Skill Development Initiatives:

Skill development initiatives have been instrumental in equipping individuals with the expertise required for diverse industries. Over a period of time MSDE (Ministry of Skill Development & Entrepreneurship) has taken up several additional roles through multiple organizations and skilling schemes, namely PMKVY (Pradhan Mantri Kaushal Vikas Yojana), PMKK (Pradhan Mantri Kaushal Kendra), NSDC (National Skill Development Corporation), NCVET (National Council for Vocational Education and Training), JSS (Jan Shikshan Sansthan), NIESBUD (National Institute for Entrepreneurship & Small Business Development), IIE (Indian Institute of Entrepreneurship), Directorate General of Training (DGT). Annually, more than One Crore youth, have been joining and benefitting from the Skill India programme. During the financial year 2022-2023, 1,419 programmes were conducted by NIESBUD across different programme categories focused on areas of stimulation, support and sustenance of entrepreneurship development. A total number of 44,557 participants attended these programmes. During FY 2022- 23(up to December 2022),783 programmes were carried out benefiting 23703 participants by Indian Institute of Entrepreneurship (IIE), Guwahati. The impact of these programs is evident in the substantial increase in employability and entrepreneurial ventures among trained individuals. [2].

3. Digital Transformation Support:

India's digital transformation has been remarkable, with a burgeoning e-commerce industry and a vast online market. According to the Indian government's statistics, India's e-commerce revenue is expected to jump from US$ 39 billion in 2017 to US$ 120 billion in 2020, growing at an annual rate of 51%, the highest in the world. It provides a wider reach and reception across the global market, with minimum investments. It enables sellers to sell to a global audience and also customers to make a global choice. Geographical boundaries and challenges are eradicated/drastically reduced. The e-commerce industry has been directly impacting the micro, small & medium enterprises (MSME) in India by providing means of financing, technology and training and has a favourable cascading effect on other industries as well. The Department of Commerce initiated an

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exercise and established a Think Tank on 'Framework for National Policy on e-Commerce' and a Task Force under it to deliberate on the challenges confronting India in the arena of the digital economy and electronic commerce (e-commerce). The heavy investment of the Government of India in rolling out the fiber network for 5G will help boost e-commerce in India. In the Union Budget of 2018-19, the government has allocated Rs 8,000 crore (US$ 1.24 billion) to BharatNet Project, to provide broadband services to 150,000-gram panchayats. Ministry of Electronics and Information Technology (MeitY) has built a network of Common Services Centres (CSC) under the Digital India Programme. The CSC project envisages setting up at least one CSC in each of 2.50 lakh Gram Panchayats (GPs) across the country, for delivery of various Government-to-Citizen (G2C) and other citizen-centric e-Services to citizens. It is a self-sustainable entrepreneurship model which is run by village-level entrepreneurs (VLEs). As of 28 February 2022, there are 4,63,705 functional CSCs across the country[6]. On average four (4) persons are engaged at each CSC. Accordingly, around 15 lakh people are now directly or indirectly working at the CSCs across the country. Common Service Centres (CSCs) to provide digital services to rural and remote citizens. This widespread digital integration has empowered entrepreneurs to reach a broader audience, catalysing business expansion. [3].

4. Gender-Inclusive Entrepreneurship Programs:

Empowering women entrepreneurs has been a focal point of India's developmental agenda. Data from the Ministry of Skill Development and Entrepreneurship has transformed the lives of over 35.56 Lakh women through skill training; empowering them for better and secured livelihood. from skill development programs specifically designed for them [4]. National Skill Development Corporation (NSDC), the executive arm of MSDE, has also been executing fee-based pieces of training via its wide network of more than 350 training partners. The organization has been instrumental in training more than 16 lakh women in the short/long-term courses (3 months to one year), accounting for more than 40% of women amongst total trained candidates. The Directorate General of Training (DGT), an apex body under MSDE that works towards the development and coordination of vocational training and employment services at the national level, has trained over 1.84 Lakh women candidates during these years (2015 till date). Additionally, government schemes like Standup India, which facilitates loans for women-led enterprises of amount 10 lakh to 1 crore, especially women enterprises, have supported the establishment of over 105,000 women-owned businesses, generating employment opportunities and fostering economic independence[5].

Conclusion:

India's deliberate actions to support self-employment in Amrit Kaal's changing ecosystem have not only tackled significant difficulties but also laid the groundwork for a revolutionary journey. The diverse approaches designed to address inequities in gender, market reach, financial availability, and skill sets have produced notable beneficial results. These technologies' scalability, economic viability, environmental sustainability, and practicality have all been confirmed by their integration with the infrastructures already in place. As a result, there is a growing entrepreneurial ecosystem that promotes social responsibility and environmental awareness in addition to stimulating economic growth.

Summary of Findings:

- Aspiring entrepreneurs have benefited from financial inclusion, notably through microfinance programs. Millions of dollars have been given through these schemes, allowing many micro and small enterprises to prosper.
- Millions of people have been trained as a result of skill development efforts, increasing their employability and entrepreneurial potential. The Skill India initiative has made substantial contributions to this effort through numerous organizations and projects.

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- India's digital transformation, characterized by significant development in e-commerce, has enabled firms to access a worldwide audience. The Digital India program, as well as Common Service Centers (CSCs), have been critical in broadening market reach.
- Initiatives supporting gender-inclusive entrepreneurship have changed the lives of millions of women by providing them with the skills and financial resources they need to start their own enterprises. Schemes such as Standup India have accelerated the formation of women-owned businesses.
- Sustainable and green entrepreneurship, as illustrated by the rise of renewable energy businesses and the adoption of eco-friendly practices, not only generates economic growth but also helps to conserve the environment.

Future Prospects:

The future of self-employment in India appears promising and transformative. As these initiatives continue to gain momentum, several prospects come to the fore:

a) **Economic Growth:** Empowered self-employment is poised to be a significant driver of India's economic growth. The continued expansion of microfinance programs, skill development initiatives and digital transformation support will further bolster the entrepreneurial ecosystem.

b) **Social Inclusion:** Gender-inclusive entrepreneurship and skill development programs are progressively breaking down barriers and creating opportunities for marginalized communities. The focus on inclusivity is expected to enhance social equity and economic empowerment.

c) **Environmental Responsibility:** India's commitment to eco-friendly entrepreneurship aligns with global sustainability goals. As more businesses adopt green practices and invest in renewable energy, the nation will contribute to environmental preservation and a greener future.

d) **Technological Advancements:** The digital transformation is set to continue, with increased broadband access and digital infrastructure development. This will enable even more entrepreneurs to tap into the global market, expanding their reach and opportunities.

Innovation and Startups: As India becomes a hub for innovation and startups, the entrepreneurial landscape is set to diversify further. Initiatives supporting innovation and providing resources for startup growth will continue to shape the business landscape.

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Giant African Snail, *Achatina fulica* Bowdich : A Non-Insect Pest of Mulberry and its Management

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Mulberry (*Morus sp*) - the food plant of silkworm (*Bombyx mori* L) is cultivated in both tropical and temperate countries of the world. Mulberry is grown under a wide range of climatic conditions and is affected by a large number of diseases and pests and many of them are of greater economic importance. In the recent years, a non insect pest, Giant African Snail, *Achatina fulica* Bowdich is found to attack mulberry.

Giant African snails are large in size (long, narrow and conical in shape, reaching a length of 20 cm), with a light brown shell to protect the body, having brown and cream bands alternatively lined. The shell size attains up to 5-10 cm. They are nocturnal in habit and hide beneath fallen leaves, inside peeled off mulberry bark or under stones during day time and come out from hiding places during night to attack host plants and cling to the dorsal and protected surfaces of leaves.

Alternate Hosts:

The snail has very wide host range and infests crops such as Coffee, Mango, Papaya, Rubber, Cotton, Ragi, Coconut, Sunflower, Gram, Beans, Peas, Brinjal, Pumpkin, Cucumber, Cabbage, Cauliflower, Sponge gourd, Bhendi, Banana, Marigold including mulberry.

Occurrence:

Snails are active in rainy season. Though their activity is observed from August to January, the incidence is severe from October to December.

Predisposing factors:

Its conspicuous occurrence is noticed in climatic conditions with high humidity (>80%) and moderate temperature (9 - 29°C) which are more congenial for the population build up.

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Symptoms:

Giant African snails feed on tender leaves, tender bark & stem and cause damage. The infested leaves show circular holes in the centre. Such damage results in stunted growth of mulberry besides leaf yield loss. It is also established that when mulberry leaves from snail infested gardens are provided to silkworms, they consume very less leaves due to presence of mucus like substance on the leaves secreted by the pest which affects cocoon production.

Management:

- During rainy season, in the evening hours wet gunny sacks or papaya stem waste should be placed near hide outs in the garden. Next day morning, the snails hiding below these should be collected and destroyed by immersing in 25 % salt solution (1 kg salt in 4 litre water).
- Regularly remove debris from the garden to avoid snail population build up.
- Deep ploughing helps in exposing snails & their egg masses present in the soil to their natural enemies.
- Do not grow creeper crops viz., cowpea, beans, horse gram etc., adjacent to mulberry, as these crops support snails for hiding and breeding.
- Snail kill (2.5% metaldehyde) pellets are to be spread in mulberry garden in alternate rows (@ 2 to 3 pellets per spot) during evening hours in rainy season or after irrigation/sprinkler for effective management. Snail kill is commercially available as most effective molluscicide and effective in all weather conditions. About 2 kg of snail kill pellets are required to cover one acre of mulberry garden.
- Metaldehyde pellets should also be placed near snail hiding places, compost pits, dumping yards, water canals for suppression of snail population.

Note: Metaldehyde was found non-toxic to silkworms as well as mulberry and can be used without any ambiguity by the sericulturists.

Snail, Achatina fulica

Snail Kill

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Smart Irrigation Techniques to Conserve Water in Agriculture

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Smart irrigation is key to sustainable agriculture amid growing water scarcity. Using technologies like soil sensors, weather data, IoT, and AI, these systems optimize water use, reduce waste, and enhance yields. Techniques such as drip, sprinkler, subsurface irrigation, and AWD in rice farming save water and boost productivity. Mobile apps and remote sensing further improve scheduling. Though initial costs and technical hurdles exist, successful models like in Maharashtra, India, show water use cut by 40% and crop yields up 25%. Low-cost, solar-powered innovations aim to help smallholders conserve water and ensure food security globally.

1.Introduction:

Water scarcity increasingly represents a threat to agriculture globally, as conventional irrigation practices tend to result in high water waste. Smart irrigation technologies take advantage of sophisticated tools like soil moisture sensors, weather information, and automated systems to maximize water efficiency in agriculture. By providing right amounts of water at the right time and place for crops, these practices help save water, enhance crop yields, and save costs. In nations such as India, where there is a high reliance on groundwater for agricultural activities, implementing smart irrigation is vital in order to practice sustainable agriculture and maintain food security when faced with climate variability and rising water demand. Bwambale *et.al.*2022.

Definition and Significance

Smart irrigation is the use of novel technologies and innovative farming practices intended to maximize water utilization in agriculture. These systems use sensor data, weather forecasts, and automated controls to supply water exactly when and where crops require it, conserving water and making it more efficient. Contrary to older methods that tend to over-irrigate, smart irrigation systems track actual field conditions in real time to adjust irrigation schedules accordingly. This not only conserves water but also fosters healthier plant growth and increased crop yields. The idea is an important step toward sustainable farming, particularly in areas experiencing climate uncertainty and dwindling water supplies.

2.Global Water Scarcity Context

Worldwide, agriculture accounts for approximately 70% of freshwater use, and it is the biggest water-consuming sector. As the world's population is increasing and water supply is reducing due to climate change, the demand for water resources is increasing. Inefficient irrigation plays a major role in water loss due to evaporation, runoff, and deep percolation. Thus, adopting smart irrigation is imperative to reduce water scarcity, sustain food security, and ensure environmental sustainability.

Relevance to India

In India, more than 50% of the population is reliant on agriculture, and the sector contributes a major percentage of the GDP. Despite this, the sector is facing vital challenges, such as unstable monsoons, depleting groundwater resources, and inadequate irrigation systems. Smart irrigation can provide a solution with a sustainable approach through effective utilization of water by farmers, minimizing the use of unreliable rainfall, and increased productivity. With the efforts of the government and adoption of technology, India can transform its agriculture water usage and enhance food security.

Source: Pipelife.org

3. Smart Irrigation System Core Components

Smart irrigation systems rely on the marriage of various core technologies that synergistically work to improve the use of water in agriculture. The components make the use of water more efficient, reduce wastage, and get crops water exactly when they need it.

i. Soil Moisture Sensors

Soil moisture sensors are integral instruments that monitor the volumetric water content of the soil. By precisely determining the amount of water available to crops at various depths in the soil, the sensors allow farmers to irrigate only when required. Such precise irrigation prevents overwatering and underwatering, enhances the health of the crops, and saves water. The collected data can be sent wirelessly to control systems for adjustments.

ii. Weather Stations

Weather stations provide live readings of environmental parameters like temperature, humidity, rain, sunlight, and wind speed. These are utilized to calculate evapotranspiration—water loss from the plant and soil surface. Based on this rate, the farmer can schedule irrigation based on real crop requirements, avoiding excess watering.

iii. Automated Controllers

These are cloud- or digital-based systems that combine information from weather and soil sensors to control irrigation events automatically. Automated controllers provide accurate delivery of water and enable remote monitoring using smartphones or computers, making it more convenient and labor-saving.

iv. Drip and Sprinkler Systems

These systems for water delivery are the pillars of smart irrigation. Drip irrigation delivers water directly to the root zone, and sprinklers mimic rainfall. Both systems reduce evaporation and runoff and ensure efficient water use.

4. Smart Irrigation Techniques

Smart irrigation methods integrate contemporary technology with effective practices to supply water to crops in a sustainable and specific way. They are meant to minimize water loss, enhance productivity, and be suitable to specific crop and soil requirements. The four most practiced smart irrigation methods are listed below: Obaideen *et.al.*2022.

1. Drip Irrigation

Drip irrigation, or micro-irrigation, is a very efficient technique in which water is applied directly to the roots of the plants using a network of pipes, tubing, and emitters. With this technique, water is applied to the root zone of the plant with minimal loss through

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evaporation and surface runoff. Water is delivered slowly and continuously, so that it filters deep into the ground, which leads to healthier root growth and more efficient nutrient uptake. Drip irrigation is particularly beneficial for row crops, vegetables, fruit trees, and orchards. It is effective even where water is scarce and can save a lot of water—up to 50% over conventional flood irrigation. It also serves to reduce weed growth because water is only used where it's required.

2. Sprinkler Irrigation

Sprinkler irrigation simulates natural precipitation by spraying water under pressure through a system of pipes and nozzles laid out above the ground. It is in extensive use worldwide due to its flexibility to various field sizes and topographies. Sprinklers are suitable for numerous crops, such as cereals like maize and wheat, vegetables, and legumes. Water is applied evenly over the field, aiding in the maintenance of consistent soil moisture and facilitating uniform crop growth. Contemporary sprinkler systems have been developed to minimize water loss through utilization of low-pressure, high-efficiency nozzles and systems that reduce wind drift and evaporation. Though less accurate than drip irrigation, it is nonetheless a useful method in smart irrigation when combined with timers and moisture sensors.

3. Subsurface Irrigation

Subsurface irrigation uses water delivery pipes buried below the ground surface, usually at depths ranging from 10 to 50 centimeters.This system distributes water directly into the root areas of crops, avoiding evaporation losses as well as surface runoff. It is especially appropriate for deep-rooted plants like cotton, tomatoes, sugarcane, and fruits.Desirable among the advantages of subsurface irrigation is that the root zone has a consistent level of moisture, which could enhance the health and yield of crops. Also, because the soil surface is not damp, weed growth and the proliferation of fungal diseases are greatly minimized. Nonetheless, subsurface system installations can be costlier than surface irrigation, and there has to be good maintenance to avoid clogging and damage.

4. Alternate Wetting and Drying (AWD)

Alternate Wetting and Drying (AWD) is an irrigation water-saving technique that is most widely applied in rice production. Rice paddies are traditionally continuously flooded, which results in intensive use of water and methane production. In AWD, the soil is permitted to dry for a couple of days between irrigation. Water is replenished only when the soil moisture drops below a specified level.AWD can save 25–30% of water without sacrificing yield. It also decreases methane emissions by minimizing the anaerobic conditions that facilitate the production of greenhouse gases in flooded fields. This method is inexpensive, simple to implement, and applicable to smallholder farmers, thus a successful and sustainable irrigation system for rice-producing areas. Touil *et.al.*2022.

5. Smart Irrigation Technologies

As the demand to optimize water consumption in agriculture grows, a number of advanced technologies have been invented to aid smart irrigation systems. These new technologies move beyond simple automation since they combine real-time data, intelligent decision-making, and the ability to remotely manage, thus making irrigation more efficient and targeted.

1. Internet of Things (IoT) Integration

IoT technology serves as the backbone of modern smart irrigation systems through internet connectivity of different sensors, controllers, and devices. A central control unit can be connected to soil moisture sensors, weather stations, flow meters, and valves. Information gathered from these devices is sent real-time to cloud-based platforms for monitoring and analysis. This integration enables the remote control of irrigation systems from any location through a computer or smartphone, minimizing the human intervention needed. IoT supports real-time and precise water delivery in accordance with actual field conditions, saving water and enhancing crop yields.

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2. Artificial Intelligence (AI) and Machine Learning

AI and machine learning systems make irrigation more efficient through processing huge amounts of agricultural data to make predictive choices. They are able to learn from historical irrigation trends, weather patterns, soil types, and crop varieties to produce optimized irrigation plans. AI algorithms improve their accuracy over a period of time as they learn from past experiences, making sure that the water is delivered at the right moment and in the correct amount. It saves water, averts over-irrigation, and assists in maintaining steady crop development.

3. Mobile Applications

Mobile applications are now critical components of precision farming. Farmers are able to track soil moisture content, set irrigation schedules, and receive notifications regarding the status of equipment or environmental conditions through these apps. Some apps also provide water consumption suggestions based on insights created by AI. Mobile control enhances flexibility and enables farmers to react immediately to changing conditions even if they are not in the farm. (Source: farmintell.com)

4. Nano Ganesh System

Nano Ganesh is a groundbreaking Indian technology that makes it possible for farmers to operate irrigation pumps remotely through simple mobile phones, even in areas with no internet connection. It can be used to switch on and off, monitor power availability, and receive notifications—all via SMS or mobile calls. The system has made rural farmers more efficient in controlling water, cutting down on fuel expenses, and saving time, particularly in places where farms are far from homes.

6. Advantages of Smart Irrigation

Smart irrigation has several benefits that go beyond mere water conservation. These systems enhance farm efficiency and sustainability using data-based tools and autonomous technologies.

Water Conservation

One of the most promising advantages of smart irrigation is water saving. By providing just the right amount of water required by plants, these irrigation systems avoid over-irrigation and wastage. Technologies like soil moisture sensors and weather-based controllers will only provide water when needed, thus saving limited water resources. Hassan *et.al.*2024.

Increased Crop Yield

Smart irrigation ensures optimal growing conditions by keeping soil moisture levels consistent. This results in healthier plants and more productive crops. Precision watering also maximizes nutrient absorption and minimizes plant stress, leading to increased yields.

Energy Savings

Since water is utilized more effectively, excessive or prolonged use of pumps is minimized. This translates to lower energy use and reduced electricity or fuel bills, especially in groundwater-pumping-dependent farms.

Cost Reduction

Even though initial installation cost can be substantial, intelligent irrigation systems save labor, water, and energy expenses in the long term. Automated systems consume less labor and maintenance.

Environmental Impact

By reducing water runoff and nutrient leaching, smart irrigation saves local ecosystems and avoids contamination of water. This encourages sustainable agriculture.

Challenges to the Adoption of Smart Irrigation

Adopting smart irrigation in developing countries faces several challenges despite its benefits. High initial investment is a major barrier, as technologies like sensors, IoT, and drip systems are costly and often unaffordable for small farmers. Technical expertise is also required to install, operate, and maintain these systems, which many farmers lack. Additionally, infrastructure issues such as unreliable electricity and poor internet connectivity in rural areas hinder effective use. A significant gap in awareness and training further limits adoption—many farmers are unaware of the benefits or existence of smart irrigation. Without targeted outreach, demonstration projects, and hands-on training, uptake remains low. Addressing these challenges through subsidies, education, and infrastructure development is vital to promote sustainable water use in agriculture.

7.Case Studies and Future Outlook

Case Study: Maharashtra, India

Among the arid areas of Maharashtra, India, more and more farmers have implemented smart irrigation practices to enhance water use efficiency, especially for water-hungry crops such as sugarcane. An effective project was the combination of drip irrigation systems with soil moisture sensors. These sensors gave real-time feedback on soil moisture, enabling farmers to irrigate their fields only when required.

The outcome of this implementation was phenomenal:

Water use was cut by 40%, allowing farmers to adapt to more variable rainfall and declining groundwater levels.

Crop yields rose by 25%, since plants were supplied with levels of water best suited for them during the growing season. Electricity demand fell by 30%, as efficient irrigation minimized the hours pumps had to run.

Future Trends

With the global demand for water growing every year, the prospects for smart irrigation are becoming brighter. A number of trends will influence the development of such systems:

- Integration with Renewable Energy: Solar irrigation is gaining traction, particularly in off-grid regions. This is an environmentally friendly option by limiting reliance on diesel or unstable grid power.
- Affordable and User-Friendly Technologies: Manufacturers are developing simpler, cost-effective tools tailored for smallholder farmers. These technologies include basic moisture sensors, mobile-based pump controllers, and low-maintenance drip kits.
- Government Support and Subsidies: Many governments are recognizing the value of smart irrigation in improving agricultural resilience. Expansion of subsidy programs, training workshops, and digital platforms will likely increase adoption across regions.

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Soil Health Indicators for Monitoring Organic Matter

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Soil Organic Matter (SOM) is one of the main soil health determinants, affecting fertility, structure, water holding capacity, and microbial activity. Tracking SOM using different indicators of soil health—Total Organic Carbon, microbial biomass, respiration, particulate organic matter, enzymes activities, and aggregate stability—considers the overall function of soils and the sustainability of ecosystems. Indicators inform productive land management practices, such as nutrient management, tillage, rotations, and conservation practices. Regular monitoring of SOM indicators promotes sustainable agriculture, improves soil resistance to climate change, and maintains long-term productivity. This bulletin summarizes key SOM indicators and their application in the monitoring of soil health.

Introduction to Soil Organic Matter and Soil Health

What is Soil Organic Matter (SOM)?

Soil Organic Matter (SOM) is an essential soil component consisting of decomposed plant and animal residues, living and dead microbial biomass, and products synthesized by soil organisms. It is a dynamic association of substances in different stages of decomposition and is the cornerstone of soil functioning. SOM affects almost all aspects of soil behavior, ranging from nutrient cycling to physical structure, microbial activity, and environmental stability.

Soil organic matter can be separated into active (labile) fractions, which degrade in a short time and support microbial activity, and more stable (humified) fractions, which last longer and play a role

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in long-term soil fertility and structure. Cardoso *et.al.*2013

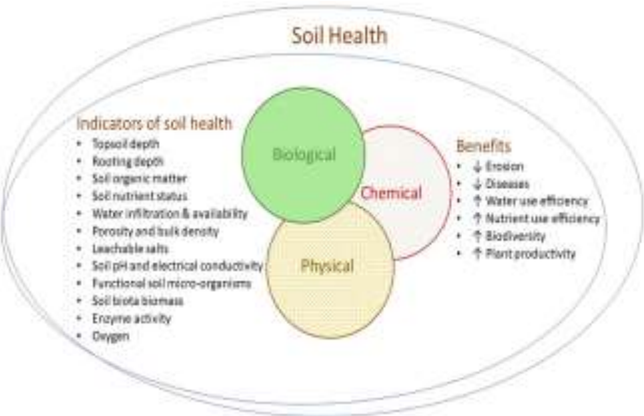
Importance of SOM in Soil Health

The presence of adequate organic matter within the soil provides several advantages that as a whole improve soil health and agricultural productivity:

- Increases nutrient availability: SOM is a pool of nitrogen, phosphorus, and sulfur nutrients available slowly to plants for uptake.
- Strengthens soil structure and water retention: By encouraging the existence of stable aggregates in the soil, SOM enhances porosity, aeration, and root water retention.
- Supports biodiversity and microbial activity: It supplies food and habitat for soil organisms, which stimulates an active and diverse microbial community that helps in nutrient cycling and disease management.
- Assists with carbon sequestration and mitigation of climate change: Soil organic matter sequesters carbon, lowering atmospheric CO_2 levels and improving resilience to climate change.

Soil Health

Soil health refers to the ability of soil to act as a living system sustaining plants, animals, and humans. It focuses on the biological health of the soil system. As SOM directly influences biological, chemical, and physical soil properties, it becomes a key indicator for assessing and sustaining soil health over time.

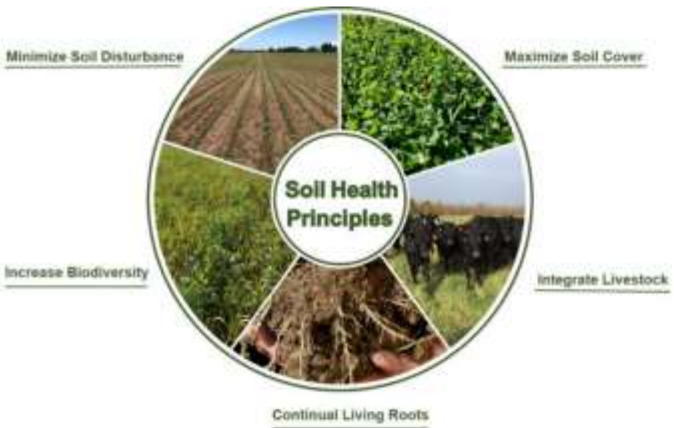


Source: www.researchgate.net/figure/Indicators-and-benefits-of-optimum-soil-health

3. Overview of Soil Health Indicators Related to SOM

What Are Soil Health Indicators?

Soil health indicators are quantifiable attributes or measurements that describe the biological, chemical, and physical status of soil. Soil health indicators assist land managers, farmers, scientists, and policy analysts to determine the extent to which a soil is performing to promote plant growth, manage water, cycle nutrients, and sustain a diverse biological community. Soil health indicators form a framework for gauging the impacts of land management practices, environmental conditions, and agricultural interventions on a sustained basis. Ditzler *et.al*. 2002 Tracking soil health via these indicators ensures soils are productive and sustainable in the long term. Of all the constituents of the soil, Soil Organic Matter (SOM) is one of the most holistic and integrative indicators because it affects several soil functions.



Source: https://humboldtrcd.org/projects/soil-health

Types of Soil Health Indicators

Soil health indicators are generally classified into three broad categories:

1. Physical Indicators

Physical signs exhibit the soil's structural state and water- and air-holding capacity. Examples are:

- Soil structure**:** Refers to the aggregation of soil particles.
- Soil texture: The sand/silt/clay particle ratio.
- Bulk density and compaction: High compaction restricts root growth and water penetration.

2.Chemical Indicators

These indicators quantify the availability of major nutrients and the chemical makeup of the soil. Important chemical characteristics are: Gerke *et.al.* 2022

- Soil pH: Affects nutrient availability and microbial activity.
- Nutrient content: Nitrogen, phosphorus, potassium, and micronutrient levels.
- Cation Exchange Capacity (CEC): The capacity of the soil to retain and exchange nutrients.

3.Biological Indicators

Biological indicators measure the activity and diversity of living organisms in the soil, such as microbes, fungi, and fauna. Examples are:

- Microbial biomass: The living portion of the soil organic matter.
- Soil respiration: Shows microbial activity and decomposition of organic matter.
- Enzyme activity: Indicates biochemical processes involved in nutrient cycling.

Why Pay Special Attention to SOM-Related Indicators?

Soil Organic Matter is closely associated with all three types of soil health indicators. Not only is it a reservoir of nutrients, but it also contributes to soil structure development and support of biological activity.

1. Relationship with Physical Properties

SOM enhances soil aggregation, erosion reduction, and porosity. It allows greater water absorption and retention by the soil, of particular relevance in rain-fed and dryland agricultural systems.

2. Effect on Chemical Properties

SOM increases the Cation Exchange Capacity (CEC) of the soil, making it possible for the soil to retain nutrients and decrease leaching. SOM organic acids also buffer pH fluctuation and affect nutrient solubility.

3. Facilitating Biological Activity

Soil biota depend on SOM as a food source. An actively managed level of SOM promotes diversity and activity in the microbial community, which is necessary for nutrient mineralization, suppression of disease, and degradation of organic matter.

4. Management Sensitivity

SOM is sensitive to changes in management and is therefore a good early warning system for soil degradation or improvement. Management practices such as reduced tillage, addition of compost, and cover cropping have direct and quantifiable impacts on SOM concentrations.

4. Monitoring SOM Key Indicators

Monitoring Soil Organic Matter (SOM) effectively demands the application of certain, dependable indicators that capture the amount and quality of organic matter in the soil. The next three indicators are the most commonly applied in research and field monitoring:

1. Total Organic Carbon (TOC)

Total Organic Carbon (TOC) is the main constituent of SOM and is the quantity of carbon in organic constituents in the soil. It is an indicator of soil fertility, structural stability, and bioactivity. More TOC usually corresponds to greater nutrient availability and healthier soil. TOC is usually analyzed by dry combustion (for example, with a CHN analyzer) or spectroscopic analysis, giving a quantitative measurement of organic carbon content. Lal *et.al.* 2004

2. Soil Respiration

Soil respiration quantifies the release of CO_2 from soil organisms while they break down organic materials. It is used as a direct measurement of microbial function and SOM turnover. High respiration rates indicate active biological processes and a healthy microbial community. This is typically measured by the accumulation of CO_2 over time with the help of chambers or infrared gas analyzers.

3. Microbial Biomass Carbon (MBC)

MBC measures the carbon found in the living microbial portion of the soil. It serves as a sensitive, short-term indicator of SOM change caused by land use or management practice. MBC is generally measured using the fumigation-extraction method.

5.Additional Indicators for SOM Monitoring

Apart from Total Organic Carbon (TOC), Soil Respiration, and Microbial Biomass Carbon (MBC), there are some other indicators that give greater information on the quality as well as dynamics of Soil Organic Matter (SOM). These indicators assist in assessing how the soil reacts to land management practices and environmental conditions over a period of time. Sullivan *et.al.*2019

4. Particulate Organic Matter (POM)

Particulate Organic Matter is made up of partially decomposed organic residues which are light in density and coarser in particle size compared to humified organic matter. POM is the most labile (easily degradable) fraction of SOM and very sensitive to recent additions, e.g., crop residues or compost. Due to its rapid turnover time, POM is a sensitive indicator of soil management changes and shows the current availability of fresh organic substrates for microbial utilization.

5. Soil Enzyme Activities

These include dehydrogenase, β-glucosidase, and phosphatase, which are responsible for the degradation of organic matter and nutrient cycling processes involving carbon, nitrogen, and phosphorus, respectively. Analysis of enzyme activities gives an indication of microbial function and the ability of the soil to degrade organic material. Enzyme activity is frequently utilized in evaluating the biological health and fertility potential of SOM level-influenced soils.

6. Carbon to Nitrogen Ratio (C:N Ratio)

C:N ratio is the ratio of carbon to nitrogen in organic matter. The C:N ratio has a great influence on decomposition rates and nutrient mineralization. A low C:N ratio (10:1 to 15:1) normally causes more rapid microbial decomposition and release of nutrients, whereas a high ratio (above 25:1) retards decomposition and immobilizes nitrogen. The C:N ratio is responsible for the stability and eventual duration of SOM in the soil. Obalum *et.al.* 2017.

7. Aggregate Stability

Soil aggregates are aggregates of soil particles held together by microbial by-products and organic matter. Stable aggregates enhance water penetration, hinder erosion, and aid in root growth. High stability of aggregates indicates favorable SOM content and the physical strength of the soil in different climatic and management conditions.

6. Methods of Measurement and Sampling

Soil Organic Matter (SOM) monitoring needs routine sampling protocols and good laboratory technique to provide consistent, comparable data. Depth, timing, and sampling technique have a significant impact on results and interpretation.

Sampling should be at a consistent depth, often 0–15 cm, because this horizon has the most active organic matter and is most responsive to land management. In order to avoid contamination, plastic or stainless steel tools should be clean, and an effort should be made to keep from mixing soil layers or bringing surface residues into the sample. Sampling should be done in the same season every year and under comparable moisture levels to minimize variability due to weather or plant growth cycles.

Measurement methods differ according to the SOM indicator. Total Organic Carbon (TOC) is usually determined by dry combustion or chemical oxidation (Walkley-Black method). Microbial Biomass Carbon (MBC) is determined by the fumigation-extraction method, while soil respiration is determined by CO_2 evolution using alkali traps or infrared gas analysis. Particulate Organic Matter (POM) is isolated by density fractionation, enzyme activity is determined through colorimetric assays, and aggregate stability is determined by wet sieving.

7. Application in Agricultural Management

Soil Organic Matter (SOM) monitoring using soil health indicators provides farmers and land managers with critical information to enhance productivity, sustainability, and environmental well-being. Indicators not only indicate existing soil status but also inform management decisions that support improved soil function and resilience in the long term.

Applying Indicators in Practice

Indicators such as Total Organic Carbon (TOC) and Microbial Biomass Carbon (MBC) inform nutrient management by identifying the soil's nutrient release potential, helping reduce dependence on synthetic fertilizers while optimizing cost efficiency. SOM changes and aggregate stability measurements direct tillage and residue management practice in favor of less tillage to conserve soil structure and avert erosion.Soil respiration and Particulate Organic Matter (POM) content indicate the efficiency of cover cropping and crop rotation since they promote increased organic matter and microbial activity. Further, comparing SOM indicators assists in determining the role of conservation measures such as no-till practice, compost use, and buffer strips towards improving soil quality. Veum *et.al.* 2014.

Case Study: Organic Farm in Midwest USA

A Midwestern organic farm applied reduced tillage and incorporated compost into its operations. After five years, TOC rose 20% and soil respiration doubled, which suggests increased microbial activity and more efficient organic matter cycling. These findings demonstrate the merits of regenerative soil management.

Decision-Making Tools

Agriculturists can utilize tools such as USDA Soil Health Assessment Protocols, the NRCS Soil Health Card, and online platforms to track soil health information and make strategic management decisions.

8. Conclusion and Recommendations

Soil Organic Matter (SOM) monitoring using various indicators of soil health gives an overall idea about the physical, chemical, and biological properties of soil. This integrated strategy is essential for maintaining productive soils, resilience to climate change, and ecosystem service support. For the maintenance of healthy soils, regularly monitoring SOM-related indicators with a balanced set of measures is necessary. Land management needs to be modified in accordance with the findings to enhance soil regeneration and fertility. In addition, education and involvement of communities are essential to promoting widespread use of soil health monitoring for sustainable land management for generations to come.

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Agri-entrepreneurship Opportunities for Rural Youth

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Agri-entrepreneurship holds the potential to revolutionize the lives of rural youth, blending age-old knowledge of agriculture with contemporary business strategies and technology. With increased demand for sustainable agriculture systems and rural growth, young entrepreneurs can venture into businesses such as organic farming, beekeeping, food processing, and agri-tech. Government initiatives, training, and digital platforms also empower youth to establish viable, scalable agribusinesses. With an embracing of innovation and value-chain integration, rural youth can generate jobs, stimulate local economies, and alleviate urban migration. Agri-entrepreneurship isn't just a job-it's a road to leadership, influence, and inclusive rural development.

Introduction

Agriculture is still the lifeline of much of rural life, with enormous opportunity beyond conventional farming. For rural youth, agri-entrepreneurship offers a special chance to turn agriculture into a vibrant and rewarding profession. With the use of new technology, innovation, and value-added services, young entrepreneurs are able to diversify sources of income, enhance productivity, and earn sustainable livelihoods. This paradigm change not only benefits the youth but also tackles unemployment and rural-urban migration. Encouraged by government support and training initiatives, agri-entrepreneurship is proving to be a strong catalyst in unleashing the economic power of rural regions while promoting innovation and resilience in the agricultural sector.

The Changing Face of Agriculture

Agriculture no longer remains limited to conventional practices. It is transitioning into a thriving industry that combines business, sustainability, and innovation. With increasing demand for food globally, climate-resilient agriculture, and trackable supply chains, agriculture is becoming dynamic and market-oriented.

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Entrepreneuring is now catching up among farmers—venturing into diversified crops, direct-to-consumer markets, and additional sources of income. This change is unlocking enormous opportunities for those who are willing to innovate in the agricultural sector. Shivacharan *et.al.* 2014.

Source:https://government.economictimes.indiatimes.com

The Rural Youth Opportunity

Rural regions host a vast number of young people, many of whom are hindered in their search for quality employment. Agri-entrepreneurship presents a realistic and empowering alternative. With land access, profound knowledge of local ecosystems, and the capacity for innovation in new technologies, rural youth can establish resilient livelihoods within their own communities. Whether by organic agriculture, dairy cooperatives, or agri-tourism activities, young entrepreneurs are generating employment not just for themselves but others around them—directly contributing towards rural development. Patil *et.al.* 2021.

Role of Innovation, Technology, and Value Chains

The growth of agri-tech is re-engineering the value chain in its entirety. From mobile-enabled crop advice services and precision irrigation to drone mapping and AI-driven forecasting, technology is facilitating smart farming and informed decision-making. In addition, enhanced logistics, cold storage, and access to e-marketplaces are enabling small producers to reach large markets. Agri-entrepreneurs who access these innovations are better positioned to manage losses, boost profits, and expand their impact.

3. Best Agri-business Ventures for Youth

Headline: Future Agri-business Concepts for Rural Youth

Young people in rural areas today have access to an increasing variety of lucrative, sustainable, and scalable agri-business ventures. With proper training, resource access, and some innovation, such ventures can provide stable revenues, encourage local development, and turn agriculture into a fulfilling career choice. Following are some of the most viable agri-business concepts that are apt for young rural entrepreneurs: Nade *et.al.*2021.

Organic Farming

With the growing demand for chemical-free, healthy food, organic farming is picking up. Young people can begin small, employing local resources and organic materials, and selling directly in local or urban markets at a premium price.

Mushroom Cultivation

Mushrooms are cultivated in contained environments and take up little land. This low-investment, high-yield opportunity is perfect for young people, particularly where agricultural land is scarce. Types such as button and oyster mushrooms enjoy high market demand.

Beekeeping and Honey Production

Beekeeping does not take much space and gives double returns in terms of honey production and crop pollination. Natural honey finds demand for health and wellness products. With training, youngsters can produce value-added products such as flavored or herbal honey.

Aquaculture and Fisheries

Fish farming is a very lucrative enterprise, particularly in water-rich areas. Methods such as biofloc farming allow fish to be grown in smaller, controlled spaces. Fresh fish and processed fish products have ongoing demand.

Agri-tourism

Agri-tourism marries farming and hospitality. Young people can create small farm-stay experiences, host tours, or demonstrate traditional methods of agriculture. Not only does it provide income but also raises visibility around rural living and sustainability.

Herbal/Medicinal Plant Cultivation

Ayurveda and herbal well-being are on the rise. Plant cultivation of herbs such as tulsi, ashwagandha, and aloe vera can prove to be a high-return business when allied with herbal product manufacturers or pharma companies.

Poultry and Livestock

Rearing poultry or small ruminants like goats or dairy cattle continues to be one of the most consistent rural enterprises. With appropriate care, disease control, and market access, it can provide year-round income.

4. Technology & Innovation in Agriculture

Headline: Smart Farming: Bridging Tradition with Technology

Technology in the current agricultural sector is not merely an addition—it's a driver of change. Smart agriculture is transforming how we farm, deal with, and sell agricultural produce, particularly for young agribusinesses. Through blending knowledge with the latest technology, rural business owners can improve productivity, cut losses, and have more control over farm activities and returns.

Utilization of Drones, IoT, and Mobile Apps

Drones are increasingly being employed to monitor crops, assess plant health, and even spray fertilizers and pesticides with accuracy, at lower costs and with lower environmental damage. IoT devices—like soil sensors and weather monitors—are assisting farmers in taking informed decisions on irrigation, fertilization, and harvesting. Mobile apps offer real-time advisory services, market prices, weather forecasts, and disease warnings, all in the palm of your hand.

Hydroponics and Vertical Farming

Urban and space-limited regions are witnessing increasing adoption of soil-less agriculture techniques such as hydroponics and vertical farming. These technologies enable plants to grow based on nutrient-rich water solutions in stacked layers, achieving high yields per square foot. For limited land youth, these technologies provide year-round cultivation with less water consumption and increased efficiency.

Digital Marketplaces for Farm Produce

It has never been easier to sell directly to consumers or institutional buyers. Online platforms now link farmers with markets, enabling them to cut out intermediaries and get improved prices. Apps and online stores manage everything from orders to payments, injecting transparency and scalability into rural agri-businesses.

Precision Agriculture

Precision farming employs data analysis, satellite imaging, and AI to make every element of agriculture more efficient—from selecting ideal crop species to forecasting yield. The method lowers input prices, enhances soil fertility, and boosts overall efficiency. Technologically skilled youth can use this technology to be agri-consultants or service providers, further widening their business scope.

Visuals:

- Photos: Agri-drones over the fields, farmers employing mobile apps, IoT weather sensors.
- Diagram: A straight-forward, step-by-step illustration of a tech-enabled value chain-beginning from soil testing and intelligent irrigation to online sales and digital payments.

5.Government Schemes & Support Systems

Headline: Policy Support & Incentives for Agri-entrepreneurs

Government aid is crucial in supporting the dreams of rural agri-entrepreneurs. With focused schemes, access to funding, training initiatives, and subsidies, youth in rural areas are able to gain the wherewithal to initiate and expand prosperous agribusiness enterprises. Some of the most important government schemes aimed at empowering and facilitating rural entrepreneurship in agriculture are listed below.

Agri-Clinics and Agri-Business Centres (ACABC)

Operated by the Ministry of Agriculture and Farmers' Welfare, ACABC targets agriculture graduates who want to set up agri-service enterprises. The scheme provides free training, handholding, and financial

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support. Candidates eligible can access a credit-linked back-end subsidy of 44% on capital outlay. A broad array of services such as soil testing laboratories, agri-input retailing, and custom hiring centers is supported by the program.

PM Micro Food Processing Enterprises Formalization (PM-FME)

PM-FME, initiated under the Atmanirbhar Bharat Abhiyan, targets formalization of micro-sized food processing units. It promotes value addition and enhanced competitiveness of indigenous products. Youth entrepreneurs, Self-Help Groups (SHGs), Farmer Producer Organizations (FPOs), and cooperatives can avail the scheme for a 35% capital subsidy, food safety training, and branding and marketing support. The scheme is best suited for entrepreneurs venturing into food packaging, pickles, spices, dairy, etc.

Rashtriya Krishi Vikas Yojana – RAFTAAR

RKVY–RAFTAAR encourages entrepreneurship and innovation by agribusiness incubation. It finances budding start-ups and agripreneurs. Idea-stage start-ups are given grants of up to ₹5 lakh, and growth-stage ventures up to ₹25 lakh. Mentorship, technical support, and networking are also provided by incubation centers. This is an influential program for youth with scalable agri-tech or food-based innovations.

Start-up India and Mudra Loans

Start-up India offers a platform for entrepreneurs to register and avail tax relief, incubation facilities, and simpler compliance. Concurrently, the Pradhan Mantri Mudra Yojana (PMMY) provides loans without collateral ranging from ₹50,000 to ₹10 lakh for micro and small units. These loans enable youth to start businesses in agriculture, food processing, or rural services free from the payload of heavy collateral. Haldhar *et.al.*2023.

6. Field Success Stories

Headline: Empowering Young Agri-entrepreneurs

Young agri-entrepreneurs in rural India are showing that with the right support, innovation, and determination, agriculture can be profitable as well as fulfilling. Their stories not only motivate but also reflect practical ways in which youth are turning challenges into opportunities.

Meena Kumari – Organic Spice Farming, Tamil Nadu

Hailing from a small agricultural family, Meena chose to go the alternative way—transitioning from traditional farming to growing organic turmeric and black pepper on her family's two-acre land. She was resisted by her neighbors at first and encountered less yield. But after undergoing training under the ACABC scheme, she gained knowledge about organic farming practices and market trends. Meena now sells her spices to specialty shops in city centers and trains other women in her village.

"Believe in your land and your methods—organic takes time, but it's worth it."

Arjun Patel – Smart Crop Marketing, Madhya Pradesh

After finishing his diploma in agriculture, Arjun watched local farmers losing their profits to middlemen. He started using mobile platforms such as eNAM and AgriBazaar to enable farmers in his village to list their produce online. After training at a local RKVY incubator, he started a small agri-tech business that links farmers directly to consumers. Now, more than 150 farmers utilize his platform, and he's venturing into logistics services. Jatav *et.al.* 2023.

"Tech isn't just for cities. It's a farmer's tool now."

Nazir Ahmad – Beekeeping in Kashmir

Nazir began with two bee boxes from a village in Kashmir. Supported by the PM-FME scheme, he expanded his honey business and acquired packaging and branding skills. Nazir sells pure mountain honey branded "Kohsar Gold" in Srinagar and Delhi today. In spite of tough winters and transport challenges, Nazir's perseverance allowed him to create a niche market.

"Start small, learn fast, and keep going. Nature rewards patience."

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7. Call to Action & Resources

Headline: Start Your Agri-entrepreneurial Journey Today!

The future of agriculture lies in the hands of young, passionate entrepreneurs ready to innovate and lead. If you're ready to take the first step, here's a simple roadmap and key resources to guide your journey from idea to impact.

Startup Steps: Identify, Plan, Network, Act

1. Identify Your Interest

Select a niche-organic farming, livestock, food processing, or agri-tech. Identify what fits your ability, location, and resources.

2. Plan Your Business

Create a basic business plan: What do you make? Who buys it? How do you fund it? Take advantage of free government and startup website templates.

3. Network and Learn

Reach out to local Krishi Vigyan Kendras (KVKs), agri-incubators, and mentors. Go on model farm visits, participate in workshops, and become a part of farmer producer organizations (FPOs).

Training Programs & Support Networks

- Krishi Vigyan Kendras (KVKs) – Provide on-ground training and demos of new-age farming methods.
- NABARD Training Centres – Offer enterprise development and financial literacy courses.
- Agri NGOs – Mentor rural youth, provide input access, and value-chain linkages.
- Startup Incubators (RKVY-RAFTAAR, MANAGE, etc.) – Provide funds, expert guidance, and peer networking.

Useful Websites & Contact Info

- www.agriculture.gov.in – Ministry of Agriculture
- www.nabard.org – NABARD Schemes
- www.startupindia.gov.in – Startup ecosystem resources
- www.enam.gov.in – National Agriculture Market
- Local KVK/ATMA office contacts – On district agriculture department websites.

Motivational Quote

"The land might be old, but the ideas can be new. Be the change your village is waiting for."

Visuals

- Flowchart: Idea → Planning → Training → Funding → Execution → Market
- QR Codes/Links: Scan for agri-business templates, government schemes, or free courses
- Icons/Images: Youth in action, laptops in fields, training sessions

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Ornamental Plants in Phytoremediation: Merging Landscape Aesthetics with Environmental Recovery

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Introduction:

The problem of heavy metal pollution is worldwide, primarily due to industrialization and disruption of natural biogeochemical cycles. In addition to endangering human health and the environment, toxic contaminants originating from man-made sources are contaminating natural resources, reducing the amount of clean water, and decreasing soil fertility. Bioaccumulation is the process by which these elements build up in living things' tissues at progressively higher concentrations & causing toxic effects on soil microbes to address soil and water pollution. Phytoremediation is a sustainable approach using plants to remove contaminants from urban and rural environments. Ornamental plants can be used in areas with contamination to improve landscapes, provide a tourist option, and generate income. As these ornamental plants are fast-growing, stress tolerant, and are not intended for human consumption. Phytoremediation contains Phytoextraction, Phytostabilization, Phytofiltration, Phytodegradation, Phytovolatilization, Phytodesalination, Rhizodegradation and Hydraulic control.

Phytoremediation approaches

Phytoremediation also called as green remediation, is a technology used by plants and microbes are minimize the environmental contaminant's concentration. There are different methods by which phytoremediation occurs are detailed below.

Phytoextraction

Phytoextraction also called as Phytoaccumulation or Phytoabsorption, or Phytosequestration. Pollutants are taken up and transported by plant roots from soil/water and later accumulated in the plant parts that can be harvested.

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It is an affordable and effective technique as it is 10 times better than conventional remediation techniques.

Table 1. Ornamental plants that accumulate contaminants in the biomass

Ornamental plants	Accumulated metals	Max. tolerance concentration (mg/kg)	Metal concentration (mg/kg)			Reference
			soil	root	shoot	
Alcea rosea	Cd	100	100	136	100	Liu *et al.* 2008
Mirabilis jalapa	Cd	100	100	68	141	Yu and Zhou 2009
Taraxacum mongolicum	Cd	100	25	12	31	Wei *et al.* 2008
Melastoma malabathricum	As	40	40	570	2800	Selamat *et al.* 2014

Fig.1 (A)Alcea rosea (B)Taraxacum mongolicum (C)Melastoma malabathricum (D)Iris pseudacorus

Phytofiltration

Phytofiltration is also called rhizofiltration, blastofiltration, or caulofiltration. It is the method by which plants remove waste or contaminants from contaminated waters. Contaminants are absorbed, thereby reducing their movement to underground waters. It is advantageous because it can be used for both Hydrophytes and terrestrial plants under *in-situ and ex-situ* applications. It restricts the movement of contaminants and redirects the contaminants to shoots. Terrestrial plants are preferred due to their fibrous root system. For the remediation of Cadmium (Cd), Nickel (Ni), Lead (Pb), Chromium (Cr), Copper (Cu), and Zinc (Zn) can be remedied with this efficient method.

Ornamental plants	Contaminants	Reference
Terrestrial plants		
Limnocharis flava L.	Cd	Abhilash *et al.*, 2009
Helianthus annus L.	Pb ,U, Cs, Sr	Chhotu *et al.*, 2009 , Dushenkov *et al.* 1997
Iris pseudacorus	Cr	Caldelas *et al.* 2012
Aquatic plants		
Eichhornia crassipes	Pb,Fe,Zn	Tanjung *et al.*, 2019
Hydrocotyle umbellata L.	Ni,Cr,Cd	Bokhari *et al.*, 2022
Lemna minor L.	Cu,Cd,Pb	Bokhari *et al.*, 2016

Fig.2 (A)Limnocharis flava L. (B)Eichhornia crassipes (C)Hydrocotyle umbellata L (D)Lemna minor L.

Phytostabilization

Phyto-stabilization is also known as phyto-immobilization. It is the process by which plants are used to stabilize soil contaminants and sludge. This technique prevents the mobility of pollutants into the groundwater and reduces the bioavailability in fine-textured soil and soil with high organic content. Ornamental plants stabilize Pb, Cd, As, Cr, Cu, and Zn.

Ornamental plants	Contaminants	Reference
Mimosa caesalpiniaefolia	Pb	Ribeiro De Souza *et al.*, 2012
Tagetes patula	Fe and Cd	Chaturvedi *et al.*, 2014
Iris lactea var. chinensis	Pb	Han *et al.*, 2008
Festuca rubra	Zn, Pb, Cu	Smith and Bradshaw's,1992

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Agrostis tenuis		
Calendula officinalis	Cd	Liu *et al*., 2008
Chlorophytum comosum	Cd, Pb	Wang *et al*., 2012
Celosia cristata	Pb	Cui *et al*., 2013
Melastoma malabathricum	Pb	Selamat *et al*., 2014

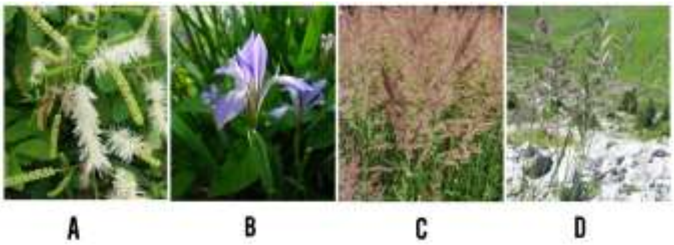

Fig.3 (A)Mimosa caesalpiniaefolia (B)Iris lacteal (C)Agrostis tenuis (D) Festuca rubra

Phytovolatilization

In phytovolatilization, soil pollutants are converted and released in the atmosphere in a volatile form through plant tissue. Unlike other remediation techniques, there is no control over the pollutant volatilized. Heavy metals such as Selenium (Se) & Mercury (Hg) as well as organic pollutants respond well to it. For example, the *Astragalus racemosus* plant converts mercuric ion into a less toxic substance and selenium into dimethyl diselenide.

Plants	Heavy metals	Reference
Typha latifolia	Se	Pilon-Smits *et al*.,1999
Stanleya pinnata	Se	Parker *et al*., 2003
Salix alba	Hg	Esbrí, J.M *et al*., 2018

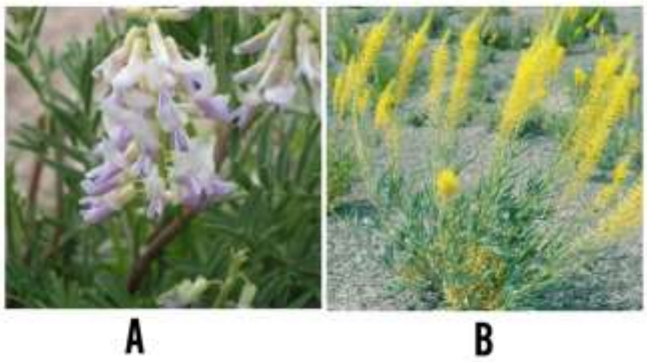

Fig.4: (A)Astragalus racemosus (B)Stanleya pinnata

Phytodegradation

In phytodegradation, plant enzymes break down the organic xenobiotic and detoxify through metabolic activities. It is an effective method in remediating contaminants like chlorinated solvents, synthetic herbicides, and insecticides.

Ornamental plants	Enzymes	Contaminants	Reference
Mirabilis jalapa	Nitroreductase	Nitrobenzene	Zhou *et al*., 2012 and Jabeen *et al*., 2009
Iris dichotoma I. lactea	Laccase	Petroleum hydrocarbon (PHC)	Cheng *et al*., 2017 and Cai *et al*., 2010
Impatiens balsamina			
Iris sibirica L.	Dehydrogenase	Carbamazepine	Tejeda and Zurita 2020
Zantedeschia aethiopica L.	Peroxidase		
Festuca arundinacea	Dehydrogenase, peroxidase, and catalase	Polycyclic aromatic hydrocarbons (PAHs)	Liu *et al*., 2014

Fig.5 (A)Iris dichotoma (B)Impatiens balsamina (C)Gaillardia grandiflora (D)Iris sibirica L (E)Zantedeschia aethiopica L

Rhizodegradation

Rhizodegradation, also known as phytostimulation. Microorganisms remediate pollutants that accumulate in the root zone or rhizosphere. The metabolic activities of microbes responsible for degradation of pollutants present in rhizosphere. Plants improve the activity and growth of micro-organisms by secreting root exudates.

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Rhizodegradation is effective in treating Polycyclic aromatic hydrocarbons (PAHs), Polychlorinated biphenyls (PCBs), Petroleum hydrocarbons, Benzene, Toluene, Chlorinated solvents, Xylenes, Ethylbenzene and Pesticides.

Plants	Microorganisms	Contaminants	Reference
Tagetes patula	*Medicago sativa Glomus caledonium*	Benso [a] pyrene	Sun *et al.*,2011, Liu *et al.*,2004
Festuca arundinacea F. gigantea	*Gordonia sp.*	PAHs	Yuanyuan Dai *et al.*,2020
Hyparrhenia hirta	*Pseudomonas fluorescens*	Cu, Zn	Conesa *et al.*,2006
Zygophyllum fabago	*Bacillus cereus*	Ni	Ghnaya *et al.*,2013

Phytodesalination

In phytodesalination, halophytic plants are used to remove salt accumulation in the soil and facilitate plant growth. Halophytic plants are more naturally adapted to handle heavy metals than glycophytic plants (plants that grow in non-saline conditions)

	Characteristics	Reference
Halophytic plants		
Suaeda maritima	Halophyte accumulating NaCl	Ravindran *et al.*, 2007
Sesuvium portulacastrum	Halophyte, accumulation of Na^+ ions	
Plumbago auriculata	They have specialized salt glands on their leaves that release too many harmful ions.	Wu *et al.*,2016
Glycophytic plant		
Hordeum vulgare	Glycophyte, negative effects on Na+ ions	Rabhi *et al.*, 2010

Salt-tolerant ornamental plants: *Antirrhinum majus*, *Petunia hybrida*, *Verbana hybrida*, *Solenostemon scutellaroides*, *Tagetes patula*, *Fuchsia hybrida*, *Pelargoium hortorum*, *Begonia hiemalis*, *Catharanthus roseus*, *Callistemon laevis*, *Portulaca grandiflora*, *Malvaviscus arboreus* var. drummondii, *Caryopteris clandonensis*, *Anisacanthus quadrifidus* var. wrightii.

Fig.6 (A)Suaeda maritime (B)Sesuvium portulacastrum (C)Plumbago auriculata(D)Pavonia lasiopetala (E)Caryopteris clandonensis (F)Anisacanthus quadrifidus

Hydraulic control

Hydraulic control is a feasible method of controlling groundwater contamination by controlling water tables and soil field capacity. Phreatophyte trees transpire a lot of water, the site's water balance is impacted. Increased transpiration therefore lessons precipitation, groundwater, migration and infiltration.

Ornamental plants for Phytoremediation

To remove trace elements	*Zinnia elegans Jacq.* *Canna indica L.* *Tagetes patula L* *Alcea rosea L.*
Used in constructed	*Heliconia rostrata*

wetland	*Pontederia crassipes* *Canna faccida* *Zantedeschia aethiopica*
To remove volatile organic compounds (VOCs)	*Chamaedorea elegans* *Scheflera arboricola* *Spathiphyllum wallisii* *Dracaena sanderiana*
To remove Heavy metals	*Euphorbia milii* *Melastoma malabathricum* *Calendula officinalis* *Tagetes patula* *Nelumbo nucifera* *Celosia cristata pyramidalis* *Iris lacteal var.chinensis*
Drought tolerant plants	*Syzygium aromaticum* *Echinacea purpurea* *Dianthus plumarius* *Rosa meillandina* *Gaillardia aristata* *Caryopteris clandonensis*
Air purifying plants	*Syngonium podophyllum* *Dracaena sanderiana* *Dendranthema morifolium* *Chlorophytum comosum* *Agave americana* *Crassula portulacea* *Hydrangea macrophylla* *Cymbidium hybridum* *Ficus macrocarpa* *Dianthus chinensis* *Hibiscus syriacus*

Research on phytoremediation using ornamental plants

- High metal concentrations in leaves were observed in two plant species are *Viola calaminaria* and *Thalspi caeulescens*.
- Mexican single, Shringer and Prajwal where tuberose varieties that showed strong accumulation and partitioning from bulb to shoot as well as tolerance to Cadmium (Ramana *et al*., 2012).
- Flower crops like *Jasminum grandiflorum, Jasminum sambac, Nerium oleander* and *agave amica* accumulate Cr from tannery effluent water. (Lai *et al*., 2010).
- *J. auriculatum* was found to be tolerant to Cr (Ramasamy, 1997).
- *Dianthus chinensis* can absorb Sulphur dioxide, while *Crassula portulacea* is capable of absorbing Benzene (Liu *et al*., 2007).
- Carbon dioxide, Benzene and Formaldehyde are efficiently absorbed and purified by *Dendranthema morifolium* & *Dracaena sanderiana*. (Shen *et al*., 2016).
- *Chlorophytum comosum*, exhibits exceptional resistance to multiple pollutants. (Wang *et al*., 2011)
- *Calendula officinalis, Lolium multiflorum, Trifolium repens,* six cultivars of *Pelargonium graveolens*, *Amaranthus hypochondriacus, Lupinus polyphyllus, Antirrhinum majus, Quamoclit pinnata, Impatiens balsamina.* (Liu *et al*., 2013; Arshad *et al*., 2008).

Conclusion

Phytoremediation helps to eliminate pollutants from the urban and rural environment. Phytoremediation using ornamental plants is an important tool to prevent heavy metal entry in the food chain, beautify the environment, and potentially remediate contaminated soils. It also helps in controlling air quality, soil quality, and water quality. Understanding the molecular mechanisms and interactions between plants and microorganisms are crucial for phytoremediation. Further studies are needed to assess ornamental quality, contamination, commercialization feasibility, and safety.

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Issues Related to Non-Repayment of Agricultural Loans by the farmers

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Introduction:

In many countries, agricultural credit follows a simple, three-tier model: the government or central bank extends funds to a specialized agricultural bank, which then on-lends to smallholder farmers, either directly or through cooperatives. Farmers use these loans to purchase inputs (fertilizer, seed, pesticides, etc.) and combine them with family labor to boost production. In theory, the extra output generates enough revenue not only to repay the loan but also to improve the farmer's livelihood. Meanwhile, the agricultural bank recovers its outlay (plus operating costs and interest owed to the government), preserving its lending capacity through a revolving fund mechanism. In practice, however, this model rarely performs as intended. Numerous studies document that agricultural output often rises only marginally—if at all—and high delinquency rates erode the fund's capital base. Loan repayments frequently fall short of covering administrative expenses, interest obligations, and defaults. As a result, credit programs become unsustainable, diverting scarce resources without delivering the anticipated benefits. This article examines the root causes of poor repayment performance in low-income countries, exploring both borrower-side and lender-side factors. By understanding where and why the model breaks down, we can identify more effective strategies for designing and implementing agricultural credit schemes that truly support smallholders and strengthen rural financial systems.

The failure of farmers to repay their loans, either on time or at all poses a serious challenge for agricultural credit institutions, especially those serving smallholders. Even the most effective strategies for expanding credit access, the best-designed incentives for lenders, and the most progressive institutional policies are rendered ineffective if repayment rates remain low. Widespread loan delinquency and default undermine long-term efforts to build sustainable lending systems for small farmers. Delinquency rates of 20–

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30% or more per year are commonly reported in smallholder credit programs, though exact default rates are often unclear (Donald, 1976). What is certain, however, is that high levels of non-repayment cripple credit institutions by eroding their financial base and deterring future lending. Beyond the financial implications, loan default also raises issues of fairness. When some farmers fail to repay their loans, the burden effectively falls on those who do, creating an unjust system in which responsible borrowers subsidize defaulters. Contrary to common assumptions, defaulters are not always the poorest or most vulnerable; they can include farmers across income levels, some of whom may exploit lax enforcement. While there are undoubtedly cases where genuine hardship, such as a failed harvest prevents timely repayment, a system that broadly tolerates non-repayment often fails to assist those truly in need. Instead, it encourages opportunism and penalizes honest borrowers. As Donald observed, leniency in repayment may appear compassionate but ultimately undermines the integrity and effectiveness of rural credit programs.

Effects of non-repayment of loans

Financial Stress for Farmers: Loan non-repayment places farmers under considerable financial strain. They may incur penalties, face increased interest rates, or become subject to legal action from lenders. This often triggers a cycle of indebtedness, making it increasingly difficult for them to recover and regain financial stability.

Reduced Access to Credit: Farmers with a history of loan non-repayment often face reduced access to future credit. This limited creditworthiness restricts their ability to invest in farm improvements, acquire essential inputs or equipment, and expand their agricultural operations, ultimately affecting their productivity and long-term growth.

Risk to Lenders: When farmers fail to repay their loans, it creates significant financial risks for lending institutions—such as banks, credit unions, and government agricultural agencies. As a result, these institutions may become more cautious or restrictive in their lending practices, reducing the availability of credit in rural areas and limiting financial support for the agricultural sector as a whole.

Impact on Agricultural Productivity: Loan non-repayment can negatively impact agricultural productivity. Without access to credit, farmers may struggle to afford quality seeds, fertilizers, or modern equipment, leading to reduced crop yields. Over time, this decline in productivity can contribute to broader economic losses within the agricultural sector.

Impact on Food Security: In certain cases, farmers' inability to repay loans can contribute to food insecurity. As financial pressure forces them to scale back agricultural activities, food production may decline, leading to reduced availability and higher prices in local markets.

Government Intervention: In many countries, governments offer subsidies, loan forgiveness schemes, and other forms of support to assist farmers. However, widespread loan non-repayment can place a significant burden on public resources, forcing governments to divert additional funds to manage the crisis or offer financial relief to struggling farmers.

Social and Psychological Impact: The inability to repay loans can deeply impact farmers and their families, leading to serious social and psychological consequences. Financial stress and the stigma of debt often contribute to declining mental health and overall well-being.

Rural Migration: In severe cases, when loan burdens make it difficult to sustain their livelihoods, some farmers may be forced to migrate to cities in search of better economic opportunities. This rural-to-urban migration can contribute to the depopulation of rural communities and create additional pressures on urban infrastructure and services.

Repayment factors:

1. **Crop Yields and Income**: For most farmers, agricultural produce is their main source of income, making loan repayment heavily dependent on the success of their crops. Various factors, such as weather conditions,

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pest and disease outbreaks, and fluctuations in market prices can significantly affect crop yields. These variables, in turn, directly influence a farmer's capacity to repay loans.

2. **Market Prices**: Farmers' incomes are closely tied to market prices for their agricultural products. Price fluctuations can significantly impact their earnings and ability to meet loan obligations. When market prices drop, profitability declines, making it more difficult for farmers to repay their loans.
3. **Input Costs**: The cost of agricultural inputs, such as seeds, fertilizers, pesticides, and machinery play a crucial role in shaping a farmer's financial stability. A significant increase in these costs can strain their budget, leaving fewer resources available for loan repayment.
4. **Loan Terms and Interest Rates**: Loan terms, such as interest rates and repayment schedules have a direct impact on a farmer's ability to repay. High interest rates or inflexible repayment conditions can lead to financial strain and increase the risk of default.
5. **Access to Credit**: Access to credit is vital for farmers. When formal lending options are limited, many are forced to turn to informal, high-interest lenders, increasing their financial vulnerability and often trapping them in a difficult cycle of debt.
6. **Financial Literacy**: A farmer's ability to make informed financial decisions is closely tied to their understanding of financial management, loan terms, and the consequences of debt. Limited financial literacy can result in poor planning and mismanagement of loans, increasing the risk of repayment difficulties.
7. **Government Policies and Subsidies**: Government policies, subsidies, and support programs are vital in supporting farmers. Initiatives such as input subsidies or loan forgiveness programs can ease farmers' financial burdens and enhance their ability to repay loans.
8. **Diversification of Income Sources**: Farmers, who diversify their income by cultivating multiple crops or engaging in non-farming activities often build a more stable financial foundation, enhancing their ability to repay loans.
9. **Extension Services and Training**: Access to agricultural extension services and training equips farmers with valuable knowledge and skills, enabling them to manage their farms more effectively and improve their loan repayment capacity.
10. **Climate and Environmental Factors**: Climate change and environmental challenges, such as droughts, floods, and soil degradation can severely disrupt agricultural production and reduce farmers' incomes, making loan repayment increasingly difficult.
11. **Family and Social Support**: During challenging times, family and community support networks play a vital role by helping farmers manage financial difficulties and offering assistance with loan repayment.
12. **Health and Personal Factors**: Personal health problems or family emergencies can divert financial resources away from loan repayment. Access to health insurance and social safety nets can help reduce the impact of these risks.
13. **Policy and Regulatory Environment**: The broader policy and regulatory framework governing agriculture and finance plays a significant role in loan repayment. Supportive policies that encourage agricultural development and promote financial inclusion can lead to improved repayment rates.

Dimensions:

Economic Dimension

- **Farm Income and Profitability**: Low farm income, volatile commodity prices, and rising

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input costs can limit a farmer's revenue, affecting their ability to repay loans.

- **Market Access:** Restricted market access or unfavorable market conditions reduce income, complicating loan repayment.
- **Seasonal Income:** Agriculture's dependence on seasonal earnings often misaligns with loan repayment schedules, creating cash flow challenges.

Financial Dimension

- **Debt Burden**: High existing debt, including multiple loans from various sources, strains farmers' finances and raises default risks.
- **Interest Rates and Loan Terms**: Unfavorable interest rates, inflexible repayment plans, and short loan durations can hinder debt management.
- **Credit Access**: Limited access to formal credit and reliance on informal lenders with high interest exacerbate repayment difficulties.

Agricultural Practices Dimension

- **Crop Failure and Production Risks**: Adverse weather, pests, and diseases can cause crop failures, reducing farmers' repayment capacity.
- **Sustainability Practices:** Unsustainable farming methods lead to soil degradation and lower yields, affecting income generation.

Policy and Institutional Dimension

- **Government Support**: The presence or absence of policies, subsidies, and support programs significantly impacts repayment rates; favorable policies help alleviate farmers' financial burdens.
- **Access to Extension Services**: Availability of agricultural extension and training improves farmers' skills, enhancing farm management and loan repayment ability.

Social and Cultural Dimension

- **Social Networks:** Family and community support can bolster farmers' financial resilience during hardships.
- **Cultural Practices**: Traditions and cultural attitudes toward debt and risk influence financial behavior.

Technological Dimension

- **Technology Adoption**: Use of modern farming technologies boosts productivity and improves repayment capacity.
- **Access to Information**: Access to market trends and best practices enables better decision-making.

Environmental Dimension

- **Climate Variability**: Climate change and unpredictable weather patterns increase risks, impacting yields and income stability.

Psychological and Behavioral Dimension

- **Financial Literacy**: Farmers' knowledge of financial management and debt affects repayment behavior.
- **Behavioral Biases**: Cognitive biases, such as over-optimism or risk aversion, influence financial decisions and repayment outcomes.

Gender Dimension

- **Gender Disparities**: Unequal access to resources and credit among female farmers can affect their repayment rates.

Health and Personal Dimension

- **Health Challenges**: Personal illness or family emergencies can divert funds away from loan repayment.

Legal and Regulatory Dimension

- **Legal Framework**: Property rights, contract enforcement, and regulatory environments impact loan repayment and lender recourse.

History of Farm Loan Waivers in India:

The earliest recorded instance of loans granted to peasants in medieval India dates back to the reign of Muhammad-bin-Tughluq (1325–1351), aimed at alleviating the hardships faced by villagers. However, due to widespread rebellion and famine,

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his successor, Firoz Shah Tughluq, chose to write off these loans.

Since India's independence, there have been only two nationwide farm loan waiver programs. The first was introduced in 1990 by the government led by V.P. Singh, costing the exchequer Rs 10,000 crore. The second, the Agricultural Debt Waiver and Debt Relief Scheme, was launched in 2008 by the UPA government, with an expenditure of Rs 71,680 crore. Following these, numerous state governments have implemented their own loan waiver schemes across the country.

State	Announced on	Limit*	Total Amount (₹ Cr)	Beneficiaries (in million)
Karnataka	July 5, 2018	2	42,165	4.3
Uttar Pradesh	Apr 14, 2017	1	36,359	4.4
Madhya Pradesh	Dec 17, 2018	1.5	35,000	4.3
Maharashtra	Aug 2, 2014	1	24,000	3.9
Andhra Pradesh	Aug 7, 2014	Full	17,000	3.3
Rajasthan	Aug 7, 2014	13,000	17,000	1.9
Telangana	Aug 7, 2014	Full	17,000	1.9
Punjab	Jun 11, 2017	13,000	10,000	3.6
Chhattisgarh	Dec 17, 2018	6,050	5,310	1.2
Tamil Nadu	May 23, 2018	1.57 lakh	5,318	1.2
Jammu & Kashmir	Jan 23, 2017	1	2.4	0.1

* Individual loan not exceeding

Rationale Behind Waiving Off Farm Loans:

- Small Land Holdings: Over 85% of small and marginal farmers in India cultivate less than 1–2 hectares of land and often lack access to essential farming inputs.
- Dependence on Monsoon: Agricultural production and crop yields in India are highly reliant on monsoon rains, making farming vulnerable to weather variability.
- Need for Credit: Given these challenges, credit becomes a vital resource for farming households to finance crop production as well as meet daily consumption and living expenses.
- Debt Trap: Farmers frequently take loans to invest in crops. However, crop failure caused by inadequate rainfall or weak market demand can push them into a cycle of debt, contributing to a rise in farmer suicides.
- Loan Waivers as a Response: In this context, farm loan waivers are seen as a necessary measure to alleviate this humanitarian crisis.

Actions can be taken for capacity build up of farmers for paying loan

- While loan waivers may offer short-term relief to a limited group of farmers, they have little potential to break the persistent cycle of indebtedness.
- There is no clear evidence that the nationwide farm loan waiver of 2008 significantly reduced agrarian distress. In the long term, improving and stabilizing farmers' incomes to strengthen their repayment capacity is the only sustainable solution.
- Durable solutions include enhancing irrigation infrastructure, developing cold storage facilities, expanding crop insurance coverage, building farm infrastructure, leveraging technology to boost productivity, and integrating agriculture with market forces and open trade.
- Addressing agrarian distress and increasing farmers' income requires urgent and sincere implementation of long-overdue agricultural reforms at the state level.
- Instead of capping loan waiver amounts, waiving only a portion of loans could help reduce moral hazard and promote responsible borrowing.
- Additionally, creative strategies are needed to transition surplus agricultural workers into more productive sectors, making farming

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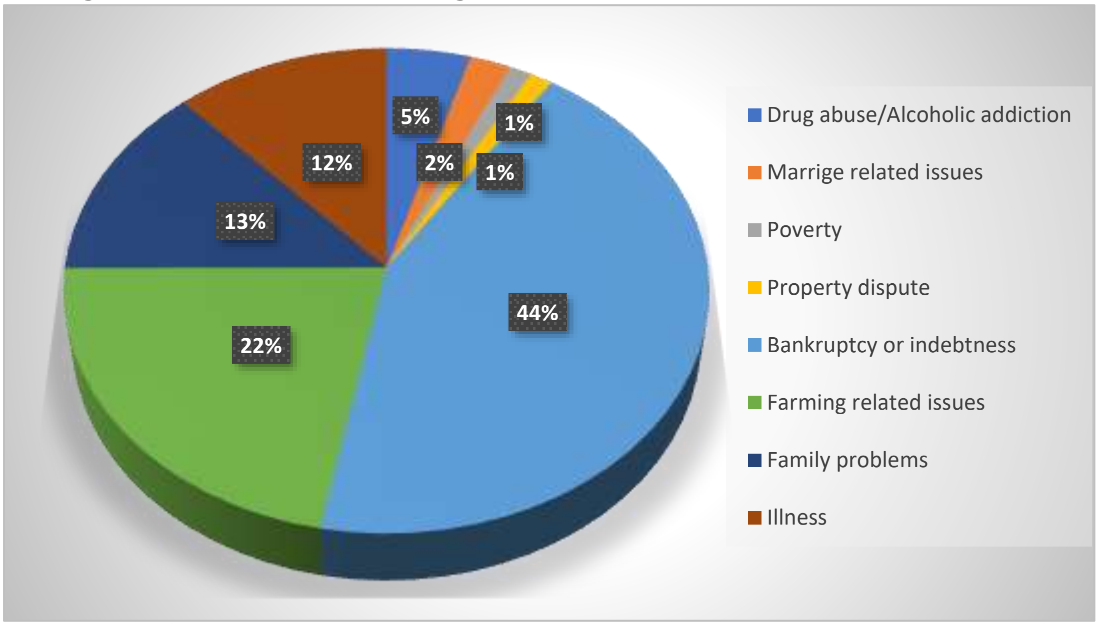
more profitable and sustainable for those who remain.

Farmers' Suicide

Indebtedness is closely linked to the tragic rise in farmer suicides, with the persistent cycle of debt exacerbating the agrarian crisis. According to the National Crime Records Bureau (NCRB) Report on Accidental Deaths and Suicides in India, 2015, a total of 8,007 cultivators and farmers took their own lives that year. Bankruptcy and indebtedness were major contributing factors, accounting for 38.7% (3,097 cases) of these suicides, while farming-related issues accounted for 19.5% (1,562 cases).

Among states, Maharashtra recorded 1,293 suicides related to indebtedness out of 3,030 total farmer suicides (42.7%), Karnataka reported 946 out of 1,197 (79%), and Telangana had 632 out of 1,538 (46.5%) in 2015, highlighting the severe impact of debt on farmers' lives in these regions.

Percentage share of major causes of Suicides among farmers/cultivators during 2015



Accidental Deaths and Suicides in India, 2015, NCRB.

Government policies to reduce the Indebtedness:

- **Increased Agricultural Credit Flow:** Agricultural credit has seen substantial growth, reaching Rs. 8,77,527 crore against a target of Rs. 8,50,000 crore during 2015-16. For 2016-17, the target was set at Rs. 9,00,000 crore, with Rs. 7,55,995 crore achieved by September 2016.
- **Kisan Credit Card (KCC) Scheme**: To ensure timely and hassle-free credit for eligible farmers, the government introduced the KCC scheme. This enables farmers to withdraw cash for purchasing agricultural inputs such as seeds, fertilizers, and pesticides, as well as meet other farming and consumption needs. By March 31, 2016, a total of 754.64 lakh KCCs had been issued by Commercial Banks, Co-operative Banks, and Regional Rural Banks.
- **Interest Subvention Scheme**: The government offers an interest subsidy to provide agriculture credit at a reduced rate of 7% per annum for short-term crop loans up to Rs. 3 lakh. Additionally, farmers who repay their loans on time receive an extra 3% subvention, effectively lowering their interest rate to 4% per annum.
- **Extended Interest Subvention**: Small and marginal farmers with Kisan Credit Cards also benefit from an extended interest subvention period of up to six months post-harvest, applicable at the same rate on loans against negotiable warehouse receipts.
- **Relief Measures for Natural Calamities**: Following RBI guidelines issued on August 21, 2015, banks are directed to reschedule loans in areas affected by natural disasters. If crop loss ranges between 33% and 50%, repayment can be extended up to 2 years,

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- including a 1-year moratorium. For crop loss exceeding 50%, the repayment period may be extended up to 5 years.
- **Promotion of Joint Liability Groups (JLGs)**: To include small, marginal, tenant farmers, and oral lessees in institutional credit, banks promote the formation of JLGs.
- **Waiver of Margin Requirements**: RBI has advised banks to waive margin or security requirements for agricultural loans up to Rs. 1,00,000, as per its circular dated June 18, 2010.

Conclusion

Indebtedness in various forms has existed for centuries and may not be the fundamental cause of the current agrarian crisis. While loan waivers can offer temporary relief, lasting solutions are essential to address the challenges faced by farmers. Rather than relying on ad hoc measures, a comprehensive series of policy interventions is needed to tackle indebtedness effectively. Key steps should focus on increasing the income of farming households through improved access to institutional credit, affordable agricultural inputs, reliable irrigation, efficient marketing systems, and robust extension services. By strengthening these areas, farmers' incomes can be enhanced, reducing their reliance on loans to meet their needs and fostering long-term financial stability.

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Demographic Shifts in Agriculture: The Resurgence of Youth Engagement

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Agriculture, traditionally dominated by older generations, is witnessing renewed youth participation worldwide. Farmers aged 55+ still form the majority, but individuals aged 18–35 are increasingly drawn to farming due to environmental awareness, digital tools, and agribusiness opportunities. This article highlights the enablers behind this shift, showcases successful Indian youth-led models, and discusses policy implications.

1. Introduction

The sustainability of food systems is an issue as the world's farming population ages. The average farmer in nations like the USA, UK, and Japan is older than 55. More than 60% of farmers in India are above 60 (DownToEarth, 2021). As more and more young people move to cities and abandon farming, this trend puts agricultural innovation and continuity at risk.

But there has been a positive change in recent years. Young people from both urban and rural areas are becoming more interested in agriculture. Young people are changing the farming scene with innovations like regenerative farming, hydroponics, organic produce, and direct marketing methods because they have digital skills, entrepreneurial desire, and an environmental conscience. FAO and national agriculture departments in nations such as Kenya and India report that youth-led agribusinesses are becoming more prevalent and that enrollment in agricultural training programs is increasing.

2. Age Profile in Farming: A Global and Indian Snapshot

The farming population is aging at a startling rate on a global scale. Farmers in the United States, the United Kingdom, Kenya, and Japan are on average 57, 59, 60, and a record 67 years old, respectively (Farmer Charlie, 2023). The situation in India is reflected in this worldwide trend. Over 60% of Indian farmers are over 60, and this demographic aging has increased over the last 20 years, according to the Counterview report (2021).

Some groups, such as IFAD, present a more positive perspective by taking into account all farm workers, not only the heads of households. According to their analysis, which was based on data from 13 African nations, the average age is more like 34. It is still unknown, though, how many of these younger

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laborers farm for profit as opposed to sustenance. The increasing average age of farmers in India is further supported by visual data spanning two decades (Fig. 1), highlighting the need for generational rejuvenation.

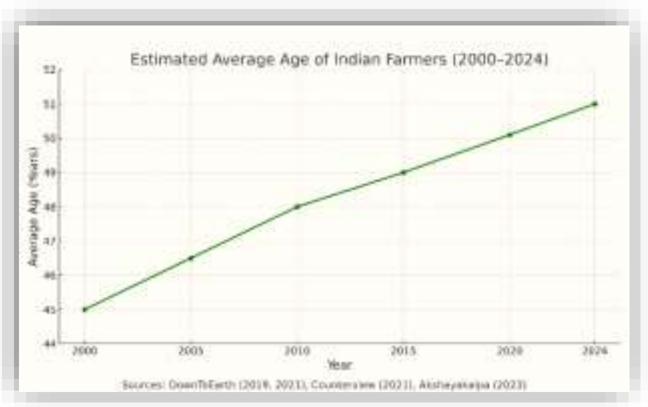

Fig 1. Average age of Indian farmers in the past two decades, a trend over twenty-four years

3. What's Driving Youth Back to Farming?

Young people's renewed interest in agriculture is mostly driven by their increased commitment to sustainability and climate action. For many young people, farming is a means of generating wholesome food and repairing ecosystems. Techniques like permaculture, organic farming, and regenerative agriculture are becoming more popular as ways to improve soil health and slow down climate change. Another important enabler is technology. The young people of today are digital natives who use sensors, drones, AI, smartphone apps, and IoT systems in their farming operations. This increases farming's accuracy, output, and appeal, particularly to people with technical or engineering expertise. The way that farming is viewed has also changed culturally. Farming, which was once thought of as low-paying, hard work, is currently being repositioned as an entrepreneurial and important endeavour. Consumer-producer interactions are changing because of ideas like farm-to-fork, local food systems, and food sovereignty.

4. Youth Agripreneurs in Action: Case Snapshots from India

4.1. Prashant Reddy (Karnataka)

An M.Tech software engineer, Prashant switched to organic farming in 2019. Serving Bengaluru's health-conscious market, he won the "Best Youth Agripreneur Award" in 2020.

4.2. ARYA Project (Nagaland)

200 tribal youth trained in piggery, poultry, mushrooms, and flowers saw rural-urban migration drop by 37%. 194 youth launched self-sustaining enterprises (₹61,000–₹4.6 lakh/year).

4.3. Tage Rita (Arunachal Pradesh)

Founder of Naara Aaba, India's first organic kiwi wine brand, Rita combined agri-engineering and local crops to build a unique value-added enterprise, now globally recognized.

4.4. Indian Young Farmers Forum (Tamil Nadu)

A mentoring collective where youth transform barren lands into food forests. One member, Pradeep, revived 5 acres using 200 edible native plants.

4.5. Sagar Dhomne (Madhya Pradesh)

Switched from GMO cotton to organic with support from WWF. Now part of a 6,000-farmer transition program empowering women to make biopesticides and fertilizers.

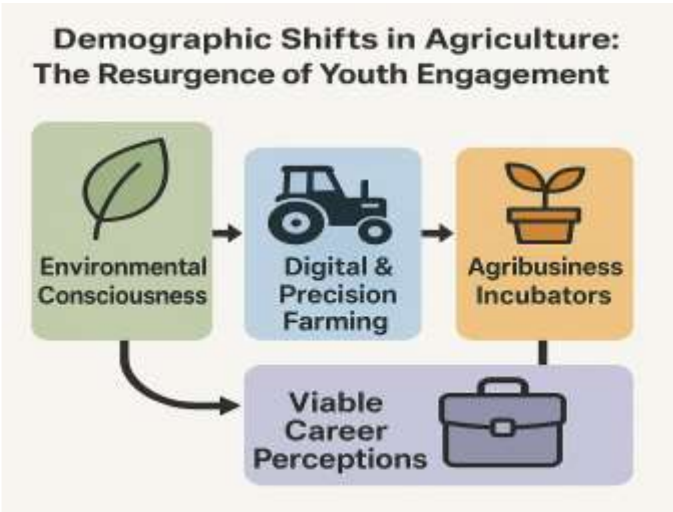

Fig 2. Key drivers behind the resurgence of youth engagement in farming as a viable interest

5. Challenges and the Road Ahead

Even with these motivational tales, difficulties still exist. Due to antiquated inheritance laws and growing land prices, young farmers find it difficult to get inexpensive acreage. Access to credit is still challenging, as many people are unable to obtain

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loans or crop insurance. Long-term commitment is also discouraged by price volatility in agricultural markets. Strategic measures are required to guarantee that this young renaissance continues. Youth-focused policies, such as adaptable land-leasing programs, agri-startup incubators, customised insurance plans, and the development of rural infrastructure, must be given top priority by governments. The next generation of farmers can be further empowered by investing in digital training and market connections.

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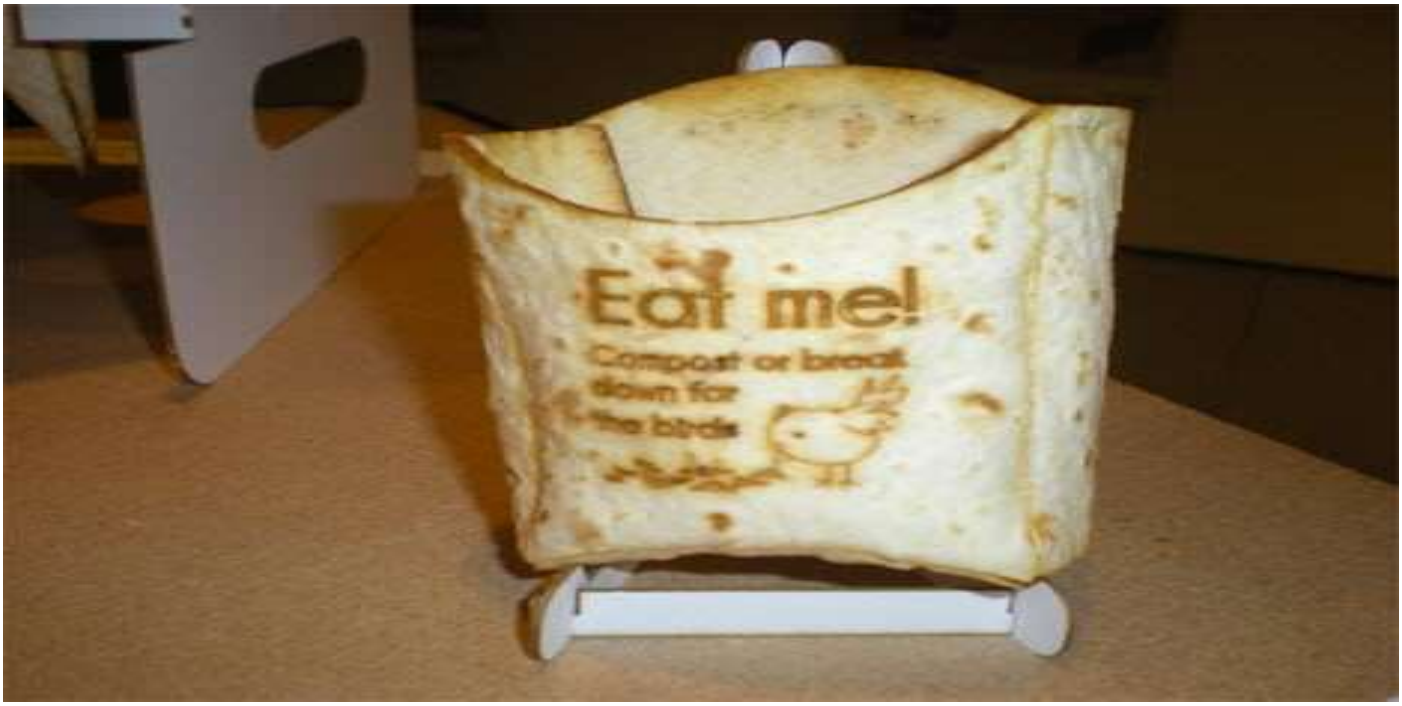

Edible Packaging and Agriculture: A Win-Win for Farmers and the Planet

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What is edible packaging?

Food-grade materials used to encapsulate items are referred to as edible packaging, which reduces waste and the need for plastic. These packages, which are made of organic materials such as fruit peels, kelp, starch, and plant-based polymers, are intended to be eaten with the food or to break down in a harmless way.

Why Is It a Viable Business for Farmers?

Farmers often face challenges related to surplus produce, fluctuating market prices, and food waste. Edible packaging offers a way to utilize agricultural raw materials, transforming them into high-value products. Here's why farmers should explore this business avenue:

Value Addition to Crops Instead of selling raw produce at lower rates, farmers can process items like cassava, corn, seaweed, and banana peels into edible packaging solutions, fetching higher returns.

Market Demand & Sustainability Trends With increasing restrictions on single-use plastics and growing consumer demand for sustainable alternatives, edible packaging is becoming a sought-after solution in food and beverage industries.

Farm-to-Package Concept By producing packaging materials directly from farm produce, farmers can create a local supply chain, reducing costs associated with transportation and intermediaries.

Steps to Start an Edible Packaging Venture

a) Identify Suitable Crops Farmers can research which agricultural products can be processed into edible packaging. Seaweed, potato starch, rice film, and fruit-derived coatings are excellent choices.
b) Develop Processing Techniques Investing in simple technology to extract polymers, mold packaging, and ensure food safety standards is crucial for product development.
c) Collaborate with Food Manufacturers Local bakeries, confectioneries, and sustainable food brands are ideal customers who may be interested in partnering to use edible packaging for their products.

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d) Secure Funding & Market the Product
Farmers can explore government grants, agricultural cooperatives, or sustainability-focused investors to scale production. Marketing efforts should highlight eco-friendliness and consumer convenience.

Challenges and solutions

1. **Costs of Production and Required Investments**

Equipment for turning crops into food-safe packaging materials is needed to start an edible packaging company. Farmers must make expensive investments in drying equipment, extraction technologies, and packing molds.

Solution: To lower initial expenses, farmers might look for government grants, agricultural subsidies, or collaborate with investors who prioritize sustainability. Creating cooperatives might aid with cost sharing as well.

2. **Technical Knowledge and Processing Expertise**

Edible packaging requires scientific knowledge to ensure food safety, durability, and shelf life. Farmers may lack expertise in developing bio-based materials.

Solution: Collaboration with universities, food scientists, and technology incubators can help farmers gain the necessary knowledge. Training programs and workshops can provide insights into best practices.

3. **Regulatory and Safety Compliance**

Since edible packaging comes into direct contact with food, it must meet strict food safety standards and government regulations. Obtaining certifications can be time-consuming and expensive.

Solution: Farmers should work closely with food regulatory agencies to understand compliance requirements. Consulting experts in food law and quality assurance can streamline certification processes.

4. **Market demand and consumer acceptance**

Since edible packaging is a relatively new idea, it can take some time for consumers to embrace it. Some consumers might be hesitant to believe that eating their packaging is safe or useful.

Solution: Consumer education and efficient marketing are essential. Adoption can be accelerated by showcasing advantages including improved food flavor, nutritional value, and zero waste.

5. **Issues with Storage and Shelf Life**

Edible packaging may have a shorter shelf life and need to be stored carefully because it is biodegradable, unlike plastic. Variations in temperature and humidity may impact its longevity.

Solution: To increase usefulness, farmers can create hybrid packaging solutions or protective coatings by combining edible films with biodegradable outer layers.

6. **The Competition from Conventional Packaging**

Due to the continued dominance of large corporations in the packaging sector, small edible packaging enterprises find it challenging to compete on price and manufacturing capacity.

Solution: To focus on specialized markets like organic food companies, environmentally sensitive

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consumers, and high-end brands prepared to spend money on sustainable packaging. Developing distinctive selling features, such as dietary advantages, can help establish distinction.

7. **Issues with the Supply Chain and Distribution**

Careful handling is necessary while transporting edible packaging to avoid spoiling. Effective logistics must be set up by farmers in order to distribute goods without sacrificing quality.

Solution: To lessen transportation issues by working with food companies for direct supply and investing in regional distribution networks. To reach more people, farmers can also look into e-commerce.

Final Thoughts

Edible packaging is more than just a trend—it's a revolutionary business model offering farmers the chance to be at the forefront of sustainability. By turning natural resources into innovative packaging, farmers can create a profitable, eco-conscious enterprise that benefits both the environment and their livelihoods.

For farmers looking to diversify and future-proof their businesses, edible packaging is not just an opportunity—it's a game-changer.

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Further Entrepreneurs' Cactus Farming in Livestock Farmers

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ICAR CAZRI KVK Pali- Marwar (Raj.)

Cactus farming for livestock farmers is an interesting and innovative concept. Cacti, especially certain varieties like prickly pear, are gaining popularity in agriculture and livestock farming for their resilience, nutritional value, and sustainability. Let's break down how cactus farming can be a good venture for livestock farmers, especially in the context of future agriculture:

Why Cactus Farming for Livestock Farmers

- **Water Efficiency**

Cactus is incredibly drought-resistant and can thrive in arid or semi-arid climates, making them ideal for areas where water scarcity is a concern. This is crucial as many traditional fodder crops require significant amounts of water.

- **Nutritional Value for Livestock**

Cactus species, particularly Opuntia (prickly pear), are high in fibre, minerals, and essential nutrients. Livestock, especially cattle, goats, and sheep, can graze on them, which provides an alternative source of fodder. They also have a low carbon footprint compared to traditional forage crops, making them environmentally friendly.

- **Fodder for Times of Feed Shortage**

During periods of drought or when traditional forage crops are scarce, cactus can serve as a reliable emergency feed for livestock. It can help maintain livestock health and productivity when other food resources are limited.

- **Economic Sustainability**

Cactus can be a high-value crop. Livestock farmers can either use it directly as fodder or explore the growing market for cactus-based products like juice, syrup, and even medicinal items, diversifying income streams.

- **Less Land Requirement**

Cactus requires minimal space compared to other crops. Its deep roots help improve soil structure and prevent erosion, which can be beneficial for land regeneration. Additionally, cactus farming can help reduce land degradation in areas where traditional farming is not viable.

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- **Climate Adaptability**

Cactus is highly adaptable to various climates, making them suitable for different regions, especially in the context of climate change. As temperatures rise, cacti could become a reliable source of feed in areas once thought unsuitable for traditional farming.

Types of Cactuses for Livestock Farming

1. Prickly Pear (Opuntia ficus-indica)

This is the most popular cactus for livestock feed. The pads (called "nopales") are rich in moisture and can be fed directly to livestock. The fruit, or "tunas," is also edible and can be used in other products.

Fig: 1. Cazri Kvk Pali-Marwar (Fodder Unit Lpm)

2. Fodder Cactus (Opuntia spp.)

Several species of Opuntia are used specifically for fodder purposes. These cacti can be grown in areas with poor soil conditions and offer high nutritional value for animals.

Fig: 2. Cazri Kvk Pali-Marwar (Fodder Unit Lpm)

How to Get Started with Cactus Farming for Livestock

1. Land Preparation

Choose well-drained, arid land where cactus will thrive. Cacti are hardy but still require proper spacing to avoid competition for resources.

Soil quality doesn't need to be rich, but it should have good drainage. Cacti prefer sandy or loamy soil, and they can tolerate slightly acidic conditions.

2. Planting and Care

Cactus is typically propagated from cuttings, and they don't require a lot of fertilizers or pesticides. They should be planted in rows, with enough space for each plant to grow without overcrowding.

3. Harvesting for Livestock Feed

Pads can be harvested by cutting them from the plant. Livestock farmers should avoid over-harvesting to ensure the plant continues to produce for future feed. Cactus can be fed fresh, but it can also be dried or processed into pellets for storage during dry seasons.

4. Integration with Livestock Farming

Cactus farming can be integrated into existing livestock operations. Grazing cattle can eat the cactus pads directly, or cactus can be supplemented with other feeds to create a balanced diet.

Farmers should monitor livestock to ensure they are adapting well to the new feed source and that it does not cause any digestive issues. Proper introduction of cactus into their diet is important.

Potential Challenges

- Spines and Thorns

One of the main challenges is the spines and thorns of the cactus. Livestock may have trouble eating it unless the spines are removed or the cactus is properly processed. Some farmers use mechanical equipment to remove the thorns before feeding.

- Market Development

If you're thinking of diversifying and creating products from cactus (e.g., cactus syrup, jam, juice), it may require market development. Educating the local community or exploring export markets for cactus-based products could be a way to generate more revenue.

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- Initial Investment

Although cactus farming has a low-maintenance cost, the initial investment for land preparation and acquiring cactus varieties may be high. However, it is typically a one-time investment, and the plant's long lifespan provides long-term returns.

Future Trends and Innovations in Cactus Farming

- Cactus as a Biofuel Source

Some researchers are exploring the use of cactus as a biofuel. This could provide an additional revenue stream for livestock farmers by turning agricultural waste (like cactus pads) into renewable energy.

- Cactus for Climate Change Mitigation

As climate change makes traditional crops harder to grow, cactus farming could become a solution to maintain food security. Cacti are particularly resilient to heat and water stress, and they could be part of the broader solution for sustainable agriculture in the future.

- Cactus Products in the Food and Beverage Industry

The popularity of cactus-based foods, such as cactus water, snacks, and supplements, is increasing globally. Livestock farmers could explore value-added products, expanding beyond just the use of cactus for feed.

Conclusion

Cactus farming has enormous potential for livestock farmers, especially in regions with water scarcity or arid climates. Not only does it provide a sustainable and nutritious feed source, but it can also be integrated into broader agricultural systems to boost profitability, land regeneration, and climate resilience. For entrepreneurs, the future of cactus farming looks promising, especially with the growing interest in sustainable agriculture and eco-friendly farming practices.

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Transforming Agriculture with Advanced Micro Irrigation: More Crop with Smart Drop

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As global concerns surrounding water scarcity and food security escalate, there will be more demand for micro-irrigation to meet growing food demands. Nearly 600 million people have been affected by the ongoing water crisis, which is projected to increase by 2050, and the country's population is expected to reach 1.6 billion. Micro irrigation has emerged as a promising trend that delivers water directly to the roots of plants, reducing all water losses and tackle conflicts over water resources management. The advent of advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), and data analytics has enabled the development of smart micro irrigation systems. These systems integrate sensors, actuators, and communication networks to optimize water application, reduce energy consumption, and improve crop yields. With the integration of smart irrigation technologies, farmers can significantly save from 20 to 50% amount of water compared to traditional micro irrigation methods and traditional micro irrigation systems often rely on manual operation and lack real-time monitoring and control capabilities.

Smart micro-irrigation systems have the potential to revolutionize the way we manage water resources in agriculture. By leveraging real-time data and advanced analytics, these systems can detect soil moisture levels, weather patterns, and crop water stress, enabling farmers to make data-driven decisions and optimize irrigation schedules.

Need for smart IoT and AI based irrigation:

Water scarcity is a leading concern throughout the

world, and with depleting groundwater resources,

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reduced rainfall, and uneven water distribution, it became most dominant problem for farmers. With additional problems like field constraints, poor quality water, conveyance pipes, leakage, irregular and unplanned irrigation scheduling leading to water wastage, and affecting agricultural fields causing deterioration and resources wastage. In the current scenario many farmers are buying or borrowing additional water from nearby farmers to meet water needs, which is increasing overall farmers investment and burden to rely on searching for resources. But with integration of smart irrigation systems, farmers can obtain more yield with limited resources by optimizing scheduled irrigation with the motto right amount at the right place in the right time.

1. Smart irrigation sensors:

Smart irrigation sensors are devices that measure various environmental parameters to optimize irrigation scheduling, which reduces water wastage and improves crop health. Under plant-based sensors, leaf wetness sensors are used to detect moisture in plant leaves to prevent over irrigation and stem water potential sensors measure water stress to optimize irrigation. We have smart irrigation controllers, irrigation schedule adjustment based on real time weather data can be made by weather-based controllers and soil moisture sensor data by soil moisture-based controllers for optimization. Wireless sensor networks to enable real-time data transmission from sensors to irrigation controllers by IoT integration and cloud-based platforms for remote monitoring, data analysis, and irrigation scheduling adjustments.

Smart irrigation system solutions:

1. Raicho: small irritation controller with weather data and all soil moisture sensors integration.
2. Sky drop: uses weather data, soil moisture sensors, and flow meters to optimize irrigation.
3. Davis Instruments: offers weather station data and soil moisture sensors for irrigation practices.
4. Aqua Spy: agricultural and land scaping applications with soil moisture sensor development and irrigation management systems.

2. Automatic drip irrigation system:

A Smart drip irrigation system ensures precise application of irrigation and nutrification based on crop type, stage, and location by taking inputs from sensors, previous historic field data, satellite images and integrating machine learning algorithms. This irrigation system ensures efficient water, nutrient supply under automated operations, saving efforts and labor force. Farmers can monitor remotely for analyzing soil moisture content, crop growth and operate data driven irrigation systems. The system provides precise supply by optimizing water and nutrient use to counteract drought and climate change impacts on crops.

3. Smart sprinkler controller irrigation system:

Smart sprinkler control system is an advanced management system for irrigation optimization and reducing input waste with precise water application utilizing sensors, weather data, and machine learning algorithms. Farmers can incorporate smart timers to set and run irrigation scheduling directly from a smartphone. With irritation controller enables farmers to remote control sprinkles and can determine irrigation duration. The major advancement in sprinkler irrigation system is digitally mapped irrigation area and "prints" to plan irrigation water application precisely in required and stressed places only.

4. Center pivot irrigation system:

Center pivot irrigation is a modern and the most efficient method of irrigation for agricultural fields in large areas. In center pivot irrigation method, a circular rotating arm is used to sprinkle water over the cross in a circular pattern. The pivot is mounted

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on wheeled towers with a central water supply and a network of pipes and sprinkle's extending radially. When the center pivot moves around the field, water is sprayed evenly, providing crops with uniform distribution with controlled water supply in a continuous manner.

The center pivot system is almost automated, reducing labor requirements to minimal and basic supervision. This system can be adapted to various field typographic variations of different sizes and shapes. The integration of Internet of Things technologies and remote sensing enables farmers to monitor and control center pivot system from their smartphones. The center pivot system can be powered by solar energy, ensuring reduced carbon footprints and operational costs additionally.

5. Solar-powered irrigation system: Solar-powered irrigation systems provide farmers innovative and sustainable solutions, reducing their reliance on fossil fuels and decreasing carbon footprints. It contains solar panels to convert sunlight into electricity and charge controllers to regulate flow of energy to battery storage for later use even at night. The energy stored is utilized for pumping water and irrigation controller for automatic irrigation scheduling. Drip irrigation, sprinkler irrigation, center pivot irrigation can be integrated with solar-powered systems.

Startups offering solar-powered irrigation systems:

1. Das Energy: solar-powered irrigation systems, including on-grid, hybrid, and off-grid solutions.
2. International Water Management Institute (IWMI): develops and promotes sustainable water management practices in India.
3. CGIAR: support the development and adaptation of solar-powered irrigation setups.

Indian government initiatives: PM-KUSUM to promote adoption of solar-powered irrigation systems for farmers and provide them with subsidies and incentives.

6. Advanced smart irrigation systems in vertical farming:

Advanced irrigation methods include Nutrient Film Techniques (NFT), where plants are grown in controlled media in narrow channels with a continuous flow of nutrient-rich water. Ebb and flow (flood and drain) method in which plants are grown in a tray or bed that is periodically flooded and drained with water. Mist irrigation is used for spraying fine mist of water into plants, and aeroponics are plants grown in air while their roots are suspended in a fine mist of water and nutrients.

In these advanced irrigation systems, farmers can integrate precision irrigation controllers for optimization of irrigation scheduling using sensors and algorithms. Automated dosing systems are used for adequate nutrient application with reduced wastage. With vertical farming software, farmers can integrate data from sensors and ML systems for optimal irrigation, nutrient application, and climate control. Farmers can remotely monitor and control irrigation using wireless sensors and cloud-based platforms.

Examples:

1. Bright Agrotechs ZipGrow: A vertical farming system that uses a combination of drip irrigation and NFT with advantageous plant growth.
2. Green Sense Farms vertical farming system with collaboration of drip irrigation and LED lighting to optimize water usage and promote plant growth.
3. Bowery Farming's smart irrigation system: it integrates machine learning algorithms and IoT sensors to optimize irrigation.

7. Robotic fleets:

Robotic fleets, also known as autonomous farming fleets or precision agriculture fleets, are transforming the precision irrigation technologies for efficient application and minimal wastage of water. Farmers have an autonomous drip irrigation system by robotic fleets to automate drip irrigation, precision sprinkler systems to optimize irrigation by adjusting its application based on different influential attributes on crops, and robotic irrigation management system integrating sensors, GPS, and weather data to optimize scheduling and water application.

Examples:

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1. John Deere's See and Spray with an autonomous irrigation system uses computer vision and machine learning to detect and spray.
2. Netafim's NetBeat, which uses AI and ML to analyze sensor data and optimize irrigation scheduling.

8. Advanced water pumps:

Water pumps are integrated with technologies that vary pressure, speed, and drive, which ensures more efficient water distribution. These advanced pumps adjust their speed and pressure based on data collected in real time from integrated Internet of Things sensors. Intelligent systems optimize water pump performance, significantly reducing water loss.

9. Actuators:

Actuators are used for controlling the physical action of irrigation infrastructure. Operating values, pumps, and other irrigation equipment based on commands received from controllers. The data collected by sensors of soil moisture triggers the actuators if moisture levels reach below a predefined threshold to open water valves. Automation enhances performance efficiency and reduces the need for manual intervention.

SMART MICRO IRRIGATION MANAGEMENT SOFTWARES:

1. Software FERGON: Fertigation is a complex process and requires estimation of irrigation water requirements, drip system capacity, required nitrogen, potassium, and phosphorus nutrients and their concentration, capacity of tank and injection rate.

FERGON was developed for user-friendly, interactive fertigation system management and planning for orchard crops as well as closely spaced field crops. FERGON also calibrates fertigation duration and nutrient concentration in irrigation water.

2. Software MICROS: Software MICROS was developed using Visual BASIC 6.0 for the design and evaluation of micro sprinkler systems. It considers effective area irrigated by each micro sprinkler and its water spread, plan spacing in the field. The software guides and gives warning or messages at suitable steps of computation and ensures accurate and reliable results for design and evaluation.

3. IFSHED: a decision support system for scheduling irrigation and fertigation in drip irrigated crops. IFSHED was developed to prepare irrigation and fertigation schedule of crops by closely simulating crop water and nutrient needs on daily basis. The decision support system calibrates the crop water

management and nutrient requirement estimated from interpolated daily evapotranspiration values. Based on drip system capacities and estimated water requirement, the irrigation system is scheduled using DSS on daily, alternate day or once-a-week as per the farmers choice. The DSS requires very little data input from farmers and prepares irrigation and fertigation scheduling for the entire crop duration.

4. IRRI: The International Rice Research Institute continuously explores, develops, and promotes sustainable water management approaches and recommends the best options or combinations of technologies for farmers, advanced adoption techniques by providing field design, land gradient leveling, and irrigation scheduling using safe alternate wetting and drying micro irrigation management.

5. Software DRIPD: User-friendly and interactive software was developed in Visual Basic to design the drip system. It helps farmers to estimate irrigation water requirements, capacity of drip main line, number of drippers and lateral pipes, diameter of main and submain pipes and size of pumping unit. After loading the software, if the user wishes to design the system, then simply click the yes button and proceed further for designing the system.

Smart irrigation technologies and systems offer numerous benefits, yet there are also some disadvantages and limitations to consider:

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1. High Initial Cost: Smart irrigation systems can be expensive to purchase and install, making them less accessible to small-scale farmers or homeowners with limited budgets.
2. Complexity: Smart irrigation systems often require technical expertise to install, program, and maintain, which can be a barrier for users without technical knowledge.
3. Dependence on Technology: Smart irrigation systems rely on sensors, software, and other technologies that can malfunction or be affected by environmental factors, such as extreme temperatures or electromagnetic interference.
4. Data Security Concerns: Smart irrigation systems often rely on cloud-based data storage and transmission, which can raise concerns about data security and privacy.
5. Limited Compatibility: Smart irrigation systems may not be compatible with all types of irrigation systems or equipment, which can limit their adoption.

Future directions:

1. Improve affordability and accessibility: Develop more affordable, user-friendly smart irrigation systems with technical support and training sessions for farmers to install, perform, and maintain systems.
2. Develop more robust and reliable technologies: Improving the durability and reliability of smart irrigation system components with robust data security protection for farmers.
3. Improve compatibility and scalability: Developing smart irrigation systems that are compatible with a wider range of irrigation systems and equipment, and can be scaled up or down depending on user needs.

Conclusion:

Smart irrigation systems with IoT based automation offer a wide array of benefits that significantly enhance water management in agriculture. Integrating advanced technologies like sensors, data analytics, and automation ensures efficient water usage with improved yield and resource conservation. Farmers can monitor over soil moisture, temperature, and weather conditions in real time for irrigation optimization to provide precise irrigation and prevent overflooding. Data driven decision-making IoT technologies help farmers to make informed management practices. Customization and scalability can be tailored to meet the specific needs of individual farms, cater to different crop types and soil conditions. These sustainable agriculture practices help reduce environmental impact. Smart irrigation systems can be scaled to accommodate increased demand, making them a flexible solution for both small and large agricultural enterprises.

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Transforming Agriculture: Precision Machinery for Enhanced Productivity

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Precision agriculture, often referred to as precision farming or site-specific crop management (SSCM), is an innovative farming strategy that enhances resource efficiency by applying inputs like water, nutrients, and crop protection chemicals in varying amounts across a field according to localized requirements. This approach boosts farm productivity, economic returns, and environmental sustainability while reducing ecological harm. The article investigates the primary technologies underpinning precision agriculture, such as GPS, sensors, unmanned aerial vehicles (UAVs), data processing tools, and automated machinery. These tools facilitate accurate management of agricultural tasks by leveraging real-time data, thereby optimizing resource use. Innovations in farm equipment, including self-driving tractors and Variable Rate Application (VRA) systems, significantly contribute to higher crop yields and lower operational expenses. The article evaluates the advantages of precision farming, such as enhanced productivity, ecological benefits, and cost efficiencies, while addressing barriers like high startup costs, data handling complexities, and connectivity limitations. As precision agriculture advances, it holds substantial promise for addressing global food security needs while minimizing agriculture's environmental impact.

Introduction

Precision agriculture, also known as precision farming or site-specific crop management (SSCM), involves tailoring agricultural practices and inputs—such as seeds, fertilizers, and pesticides—to the unique conditions of different areas within a field. By adjusting these inputs to match specific site requirements, this method optimizes crop production while reducing waste. This approach minimizes excessive or insufficient application of agrochemicals, thereby improving profitability and mitigating environmental degradation.

In the early 20th century, researchers began exploring variations in soil characteristics, such as nutrient availability and organic matter, and their influence on crop performance. For example, in the

1920s, the University of Illinois in the United States encouraged farmers to map soil pH differences across their land and adjust lime applications accordingly (Linsley & Bauer, 1928). Despite ongoing studies on soil and yield variability, the rise of mechanized farming and the use of larger machinery led to the treatment of expansive fields as uniform units, often ignoring inherent spatial differences.

Precision agriculture integrates cutting-edge technologies to optimize resource utilization, including water, fertilizers, and pesticides. By employing data-informed strategies, farmers can customize their operations to suit the distinct needs of their crops and soils, enhancing efficiency, sustainability, and economic viability. Agricultural engineering has been pivotal in driving this technological transformation, with advancements in farm machinery enabling precise control over farming activities.

With escalating global food demands, environmental challenges, and labor constraints, precision farming has become essential to contemporary agriculture. This article delves into the major technological innovations in farm equipment and their contributions to precision agriculture, analyzing their effects on productivity, environmental stewardship, and the future trajectory of farming.

The Concept of Precision Farming

Precision agriculture employs a suite of technologies aimed at optimizing farm operations. Its central objective is to improve crop production efficiency by using detailed insights into soil conditions, crop status, weather patterns, and resource demands. Unlike traditional farming, which often apply inputs uniformly across fields, precision agriculture recognizes each segment of a field as having unique requirements. The key technologies driving this approach include Global Navigation Satellite Systems (GNSS), environmental sensors, remote sensing, UAVs, data analytics, and robotic systems. These tools allow farmers to gather, process, and act on data in real time, resulting in more precise and resource-efficient farming practices.

Key Technologies Driving Precision Farming

1. **Global Navigation Satellite Systems (GNSS)**: GNSS technology is fundamental to precision agriculture, enabling farmers to accurately locate machinery within a field for precise application of seeds, fertilizers, and pesticides. Integrated into equipment like tractors, harvesters, and sprayers, GNSS ensures operations follow predefined routes with high precision. GNSS-enabled machines can operate autonomously, minimizing manual labor and ensuring consistent resource application. For instance, auto-steering systems use GNSS to guide machinery along optimized paths, reducing overlaps and input waste, which lowers fuel costs and enhances operational efficiency.
2. **Sensors and IoT Integration**: Sensors are critical for monitoring environmental parameters such as soil water content, temperature, humidity, and plant health. Soil moisture sensors, for example, assess water levels in the soil, guiding irrigation decisions. Connected via Internet of Things (IoT) networks, these sensors transmit data to cloud platforms for analysis, enabling farmers to adjust irrigation, nutrient application, and pest control based on real-time conditions. This precision reduces water and chemical overuse, mitigating environmental impacts. An example is the Soil Water Sensor, which measures moisture at various soil depths, allowing farmers to tailor irrigation schedules to specific field zones.
3. **UAVs and Remote Sensing Technologies**: Unmanned aerial vehicles (UAVs), or drones, equipped with high-resolution cameras, multispectral sensors, and thermal imaging, provide aerial field surveys. These tools generate data on crop health, identifying issues like nutrient deficiencies, diseases, or

pest outbreaks early. Multispectral imaging captures light across various wavelengths, revealing plant stress invisible to the naked eye. By analyzing these images, farmers can monitor crop vigor, detect problems, and optimize harvest timing, improving yields and reducing losses. UAVs also create detailed field maps, showing variations in soil type, moisture, and elevation, which inform Variable Rate Application maps for precise input adjustments.

Advancements in Farm Machinery

1. **Autonomous Tractors and Equipment**: The advent of autonomous tractors and machinery represents a significant leap in farm technology. Equipped with GNSS, sensors, and sophisticated algorithms, these machines perform tasks like plowing, planting, spraying, and harvesting with minimal human input. Autonomous equipment enhances labor efficiency, particularly in regions facing labor shortages, and reduces human error, ensuring high-precision operations. For example, autonomous tractors from manufacturers like John Deere use machine learning to adapt to field conditions, allowing remote monitoring via mobile devices, which offers farmers operational flexibility.
2. **Variable Rate Application (VRA)**: VRA technology enables machinery to adjust the application rates of fertilizers, water, and pesticides based on field-specific data from sensors, satellite imagery, or soil maps. This ensures inputs are applied only where needed, reducing costs and environmental impacts like nutrient runoff. For instance, a VRA-equipped fertilizer spreader adjusts nutrient application rates according to soil fertility levels, optimizing resource use and minimizing waste.
3. **Smart Irrigation Systems**: Efficient water management is vital in precision agriculture, especially in water-scarce regions. Smart irrigation systems integrate data from soil moisture sensors, weather forecasts, and crop water requirements to optimize irrigation schedules. These systems automatically adjust water delivery, ensuring crops receive precise amounts, reducing waste. For example, a Soil Moisture Monitoring Network combined with weather data enables targeted irrigation, conserving water and improving crop health.
4. **Robotic Harvesters**: With declining agricultural labor availability, robotic harvesters address workforce shortages by autonomously harvesting crops like fruits and vegetables. Using computer vision, artificial intelligence, and machine learning, these robots identify ripe produce and harvest it without damaging plants. For instance, robotic berry harvesters scan fields to pick ripe fruit, operating continuously to enhance efficiency and reduce reliance on seasonal labor.

Benefits of Precision Farming

1. **Increased Yield and Efficiency**: Precision agriculture optimizes resource use by tailoring inputs to specific field conditions, minimizing waste and maximizing crop yields. Technologies like GNSS-guided planting ensure optimal seed placement, improving crop establishment and productivity.
2. **Environmental Sustainability**: By reducing the overuse of fertilizers, pesticides, and water, precision farming minimizes environmental harm. Targeted application prevents chemical runoff into water bodies, and smart irrigation conserves water resources, promoting sustainable practices.
3. **Cost Reduction**: Precision technologies lower operational costs by optimizing resource use. GNSS-guided machinery reduces fuel consumption, and VRA

4. minimizes input expenses, enhancing farm profitability.
5. **Data-Driven Decision Making**: Precision farming leverages data analytics to provide real-time insights, enabling farmers to make informed decisions on planting, irrigation, and pest management. Historical data supports long-term planning, improving farm management.

Challenges of Precision Farming

Despite its benefits, precision agriculture faces several obstacles:

1. **High Initial Costs**: The investment in advanced equipment, sensors, and software can be prohibitive, particularly for smallholder farmers, despite long-term savings.
2. **Data Management**: The large volume of data generated requires sophisticated tools and expertise for analysis, posing challenges for farmers without technical training.
3. **Connectivity Issues**: Limited internet access in rural areas can hinder real-time data transmission and the use of IoT-based technologies, limiting adoption.

Conclusion

Precision agriculture marks a transformative shift in farming practices, driven by advanced machinery, sensors, GNSS, and data analytics. These technologies enhance efficiency, reduce costs, and promote environmental sustainability. While high initial costs and technical challenges remain, the long-term benefits position precision farming as a critical solution for meeting global food demands while minimizing agriculture's ecological footprint. Ongoing innovation will further shape a data-driven, automated, and sustainable future for agriculture.

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Biochemistry of Nitrogen Fixation: The Role of Nitrogenase and Rhizobium

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Nitrogen is a vital nutrient for plant growth, being a fundamental part of proteins, amino acids, nucleic acids, chlorophyll, and various enzymes. Although nitrogen gas (N_2) makes up about 78% of the Earth's atmosphere, it is chemically inert and cannot be directly used by most living organisms. For plants to use nitrogen, it must first be converted into forms like ammonia (NH_3), nitrate (NO_3^-), or ammonium (NH_4^+).

Nitrogen fixation is the biological process that converts atmospheric nitrogen into usable forms like ammonia. This transformation is performed by certain microorganisms, including free-living and symbiotic species. One of the most important examples is the symbiotic relationship between Rhizobium bacteria and leguminous plants. In this association, Rhizobium reduces atmospheric nitrogen to ammonia through the action of a special enzyme called nitrogenase, functioning under low-oxygen conditions inside root nodules.

This article explores the biochemistry behind nitrogen fixation, focusing on the key roles of Rhizobium and nitrogenase, and discusses how this natural process supports sustainable farming practices.

Biological Nitrogen Fixation (BNF)

Biological nitrogen fixation plays a critical role in maintaining soil fertility and reducing reliance on chemical fertilizers. It is carried out by certain bacteria and archaea that possess the nitrogenase enzyme, enabling them to convert nitrogen gas into ammonia.

There are three main types of nitrogen-fixing organisms:

1. **Free-living nitrogen fixers** – These live independently in the soil, such as some species of Azotobacter and Clostridium.
2. **Associative nitrogen fixers** – These live in close association with plants, like Azospirillum with grasses.
3. **Symbiotic nitrogen fixers** – These live in mutualistic relationships with host plants, such as Rhizobium with legumes.

Among these, symbiotic nitrogen fixation is especially efficient and widely used in agriculture due to its high nitrogen contribution to crops.

Rhizobium and Legume Symbiosis

Rhizobium is a type of soil bacterium that forms beneficial partnerships with the roots of leguminous plants like peas, beans, lentils, and alfalfa. This interaction starts with the plant roots releasing chemical signals that attract the bacteria. In response, Rhizobium produces signaling molecules that trigger changes in the root structure, leading to the formation of infection threads and eventually, root nodules.

Inside the nodules, Rhizobium transforms into a nitrogen-fixing form called bacteroids. These bacteroids use energy and carbon provided by the plant to fix nitrogen and convert it into ammonia, which the plant can absorb and use for growth.

A key component of this system is **leghemoglobin**, a protein that binds oxygen and regulates its concentration inside the nodule. This maintains the low-oxygen environment needed for nitrogenase to function efficiently, while still allowing respiration to continue.

Structure and Function of Nitrogenase

Nitrogenase is the enzyme that enables nitrogen-fixing organisms to convert atmospheric nitrogen into ammonia. It is made up of two main parts:

1. **Iron (Fe) protein** – Supplies electrons to the reaction.
2. **Molybdenum-iron (MoFe) protein** – The site where nitrogen is reduced.

The overall reaction catalyzed by nitrogenase is:

$$\mathbf{N_2 + 8H^+ + 8e^- + 16ATP \rightarrow 2NH_3 + H_2 + 16ADP + 16Pi}$$

This reaction is energy-intensive, requiring 16 ATP (Adenosine Triphosphate) molecules for each nitrogen molecule fixed. Nitrogenase is highly sensitive to oxygen, which is why it operates in the protected environment of the nodule, where oxygen levels are strictly controlled.

There are also alternative forms of nitrogenase that use metals like vanadium or iron instead of molybdenum, each with unique properties and efficiencies.

Research Data and Advances

Numerous studies have quantified the contributions of BNF to soil fertility and crop productivity. According to Herridge et al. (2008), symbiotic nitrogen fixation contributes approximately **50 to 300 kg N/ha/year** depending on the legume species and environmental conditions.

- **Soybean Case Study:** In soybean cultivation, symbiotic nitrogen fixation can meet **60-70% of the crop's total nitrogen requirements**. In India, inoculation of soybean seeds with Rhizobium strains has led to yield increases ranging from **15% to 30%**.
- **Chickpea and Pigeonpea:** Experiments conducted by the Indian Council of Agricultural Research (ICAR) have shown that BNF in chickpea and pigeonpea can result in nitrogen savings of **40-60 kg/ha**, significantly reducing the need for synthetic fertilizers.
- **Environmental Impact:** Over-reliance on synthetic nitrogen fertilizers has led to numerous environmental problems, including nitrate leaching, water eutrophication, and greenhouse gas emissions. BNF, by contrast, is a clean and sustainable alternative that mitigates these issues.

Contributions to Agriculture

Biological nitrogen fixation is an essential process in modern sustainable agriculture. It significantly reduces the need for chemical fertilizers by naturally supplying nitrogen to crops.

Role in Major Crops:

- In legume-based farming systems, nitrogen fixation can fulfill a large portion of a crop's nitrogen needs.
- Using Rhizobium inoculants can boost yields in crops like soybean, chickpea, and pigeonpea.

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- Residual nitrogen in the soil after legume cultivation benefits subsequent crops in rotation.

Environmental and Economic Benefits:

- Reduces environmental issues linked to chemical fertilizers, such as water pollution and greenhouse gas emissions.
- Offers a cost-effective solution for farmers, especially in regions with limited access to synthetic fertilizers.
- Supports biodiversity in the soil and improves long-term soil health.

Applications in Sustainable Agriculture

1. **Reducing Fertilizer Use**: Natural nitrogen fixation lowers the dependence on industrial nitrogen fertilizers, which are costly and energy-intensive to produce.
2. **Enriching Soil Fertility**: Legumes enrich the soil with fixed nitrogen, benefiting both the current and future crops in the same field.
3. **Encouraging Crop Rotation**: Alternating legumes with cereals help maintain soil balance and boosts overall productivity.
4. **Improving Soil Microbiology**: Nitrogen-fixing bacteria enhance microbial diversity, which contributes to healthier and more resilient soils.
5. **Supporting Climate Goals**: By decreasing reliance on synthetic inputs, biological nitrogen fixation reduces the carbon footprint of agriculture and promotes climate-resilient farming.

Challenges and Future Directions

Despite its potential, several factors limit the widespread use of biological nitrogen fixation:

- **Specificity**: Rhizobium strains are often specific to particular legume species.
- **Environmental Conditions**: Factors like soil acidity, temperature, and moisture can affect the efficiency of nitrogen fixation.
- **Competition**: Introduced beneficial strains may be outcompeted by less effective native soil bacteria.

Future Opportunities:

- **Genetic Improvements**: Research aims to introduce nitrogen-fixing abilities into major cereal crops such as rice and wheat.
- **Microbial Blends**: Using a mix of beneficial microbes can enhance overall plant health and nutrient uptake.
- **Precision Use**: Soil testing and smart farming technologies can help target the use of inoculants more effectively.

With continued innovation, it may become possible to extend nitrogen-fixing capabilities beyond legumes, greatly expanding the benefits to global agriculture.

Conclusion

The nitrogen-fixing partnership between Rhizobium and legumes offers a natural and effective way to provide plants with essential nitrogen. Through this mutually beneficial relationship, atmospheric nitrogen is transformed into a usable form, supporting plant growth and enriching the soil.

This process is not only vital for agricultural productivity but also for environmental sustainability. By reducing the need for synthetic fertilizers, biological nitrogen fixation helps create farming systems that are more balanced, efficient, and ecologically sound. Looking ahead, scientific advances may unlock even more potential for this powerful natural process in the quest for global food security.

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Impact of Global Markets on Local Crop Prices

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This bulletin examines the impact of international market forces on local commodity prices, which affect farmers, consumers, and national food security. Major world drivers—like changes in supply-demand balances, trade policies, and currency movements—cause price movements to ripple across borders. Case studies in India, Nigeria, and Argentina show the different effects. The bulletin also identifies reactions such as government intervention, farmer adjustment, and infrastructure investment. It ends with policy suggestions to increase resilience and promote fair pricing in a growing interdependent agricultural economy. A comprehension of these global-local processes is necessary for sustainable development and fruitful agricultural planning.

The interconnection between international markets and domestic crop prices has become more intricate and integrated over the past few decades. As trade in agriculture has increased across borders, local farmers and consumers are today more exposed to international economic fluctuations, supply chain issues, and global trade dynamics. What were primarily regionally isolated markets a few decades ago are now highly integrated within an international system driven by demand volatility, geopolitical phenomena, and climate uncertainty. Yang *et.al.* 2008.

Local farm prices are no longer determined or isolated by local conditions like harvest output or national policy. Rather, prices of staple items like wheat, maize, soybeans, and rice are shaped by variations in international patterns of consumption, fluctuations in trade policy like tariffs or export prohibitions, and even macroeconomic indicators like currency exchange rates. For instance, a drought in a leading exporting nation may lower world supply and have a ripple effect that increases prices globally, even for countries not directly impacted by the weather condition.

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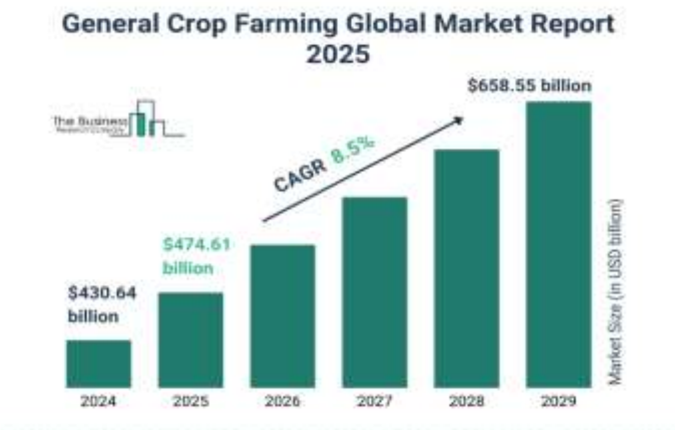
This connection with international markets also invites speculation on commodity exchanges, which further destabilizes prices for local farmers who do not have the resources or means to hold that risk. Globalization can bring access to greater markets and better income possibilities for farmers, but it also subjects them to uncertain international forces outside of their control.

Understanding how global markets influence local pricing is essential for developing effective agricultural policies, ensuring food security, and protecting farmer livelihoods. Policymakers, agricultural cooperatives, and development organizations must work together to create adaptive strategies that respond to these global-local interactions, support farmer resilience, and promote price stability in domestic food systems. Smale, *et.al.* 2009.



Source: https://www.thebusinessresearchcompany.com

3.Global Market Dynamics

The global market forces strongly influence domestic crop prices through several interlinked economic and policy channels. It is crucial for all agricultural value-chain stakeholders—farmers, traders, and policymakers alike—to comprehend these forces.

1. Global supply and demand changes

The underpinning of price behavior in the agricultural markets is global supply and demand. As global population increases—projected to reach more than 9 billion in 2050—so too is demand for staple grains such as wheat, rice, maize, and soybeans. Diet changes in developing economies are also changing patterns of consumption. In much of the developing world, incomes are improving, stimulating increased consumption of meat, and through this, indirectly driving demand for feed crops like maize and soybeans. This global consumption pattern puts upward pressure on prices and impacts local markets even in nations that aren't significant exporters or importers. Dillon *et.al.*2016.

2. International Trade Policies

Trade policies have a significant impact on shaping the flow of farm products across borders. Tariffs, export restrictions, and government subsidies distort global price signals and create uncertainty in local markets. A good example is the U.S.–China trade war, in which China taxed U.S. soybeans, causing an overabundance in the U.S. and redirecting purchases to Brazil and Argentina. This abrupt shift in trade patterns impacted soybean prices worldwide, showing how two nations' geopolitical choices can create far-reaching ripple effects on farmer revenues elsewhere.

3. Exchange Rates of Currency

Currency fluctuations equally impact crop prices heavily. A weakening local currency makes a country's exports cheaper and more attractive on the international market, potentially raising farm-gate prices. However, it also increases the cost of imported agricultural inputs such as fertilizers, seeds, and machinery. This dual effect can squeeze profit margins for local farmers and cause inflation in domestic food prices. Consequently, relative strength or weakness of a local currency can cause discrepancy between international commodity prices and local retail prices, making markets unstable and less predictable.

4.Impact on Local Crop Prices

The impact of international markets on domestic crop prices is realized through a number of complicated and frequently volatile mechanisms. As much as globalization provides opportunities for trade and

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revenue, it also introduces volatility in domestic agricultural economies. Learning how international dynamics are translated into local price adjustments is central to creating robust and adaptive food systems. Baffes, *et.al.*2015.

Source: https://www.istockphoto.com

1. Price Transmission Mechanism

One of the major mechanisms through which global markets influence local prices is the process of price transmission. When international prices for key crops such as wheat, soybeans, or maize rise or fall, local prices tend to move in the same direction. Yet the extent and rapidity of transmission differ widely depending on the crop, the organization of local markets, and the integration of the global trading system by the country. For instance, an international surge in wheat prices will increase bread prices even in nations that are not highly dependent on imports because of international reference points and psychological anticipations in the market. In contrast, in isolated markets with low exposure to trade, this impact can be delayed or suppressed.

2. Volatility and Uncertainty

Domestic farmers and consumers are also facing more exposure to price volatility resulting from global factors. Occurrences like droughts in major producing areas such as the U.S., Ukraine, or Brazil are capable of evoking instantaneous global supply shocks, leading to quick price increases. Apart from natural causes, financial speculation on international commodity markets has the effect of creating artificial price peaks. Institutional players tend to use commodities as short-term profit-making assets, and their tendency to buy and sell can lead to a sharp price fluctuation irrespective of real supply and demand.

3. Seasonal and Structural Factors

In spite of worldwide pressures, domestic realities like the local cycle of harvests, storage capacity, transportation networks, and local weather conditions play a crucial role in determining how global prices are local reflections. A local harvest bumper crop can cause an oversupply situation temporarily, driving prices lower, even where there is a shortage situation in the rest of the world. Even weak roads or scarcities of storage facilities can cause post-harvest losses, reducing farmers' capacity to take advantage of higher worldwide prices.

5. Case Studies

Case studies show the ways in which international market forces combine with local conditions and national policy to determine crop prices. The three cases below—from India, Nigeria, and Argentina—show the different ways that local agricultural markets are driven by international forces.

Case 1: India – Wheat and Rice

India's farm sector is heavily connected with international food trends, particularly in staple crops such as wheat and rice. Over the past few years, international prices of rice shot up because of weather abnormalities fueled by El Niño, which affected rice yields in major exporting nations. Consequently, one of the world's largest exporters of rice, India, came under added stress on domestic procurement and food subsidy schemes, which are vital to food security and price management. India retaliated by imposing export controls on non-basmati rice in 2023 in order to safeguard local stocks and contain inflation. The policy, though, had a far-reaching international impact—prices of rice in African nations and Southeast Asia skyrocketed, showing how a nation's domestic choices may have implications for international markets. India's dual identity as both a world influencer and an internationally price-trend-affected country makes it an interesting case of two-way price transmission.

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Case 2: Nigeria – Maize and Soybean

Nigeria's farm market mirrors the woes of import dependence and exchange rate instability. The biting devaluation of the Naira over the last few years, coupled with government bans on agro- imports to promote local self-sufficiency, caused severe price hikes for key crops such as maize and soybean. To this effect, increased international prices of soybean drove up the prices of livestock feed that is based on soybeans, impacting poultry and dairy farmers who also depend primarily on maize. This added to inflationary pressures within the food chain. These trends highlight the ways in which global market fluctuations and local monetary interventions can interact to push local food prices out of the reach of smallholder farmers and consumers.

Case 3: Argentina – Soybean and Corn

Being one of the biggest exporters of soybean and corn in the world, Argentina's crop prices are directly linked to international commodity markets. Farmers reap immediate benefits from international high prices since they produce mainly for export. Yet, the Argentinian government levies export taxes to manage local inflation and local affordability of food. Although the policies may assist in stabilizing local prices for buyers, they minimize producers' profit margins, at times deterring production and investment in agriculture. This example shows the dilemma between export revenue maximization and domestic food price stability within an interconnected world economy.

6.Responses and Policy Implications

As local crop prices are more and more influenced by global market forces, a comprehensive response to safeguard farmers and consumers from extreme volatility as well as long-term market disequilibrium is warranted. Policymakers, development agencies, and the private sector need to act together to enact policies that enhance resilience, efficiency, and equitable engagement in world markets. The following are three essential response areas: government intervention, farmer adaptation, and infrastructure development.

1. Government Intervention

Governments have a range of tools at their disposal to manage price volatility and protect food security. Price support schemes, export bans, and the use of strategic grain reserves are frequently used to stabilize domestic markets. For instance, many countries stockpile staple grains to release into the market during price spikes or poor harvests. Export restrictions, like India's 2023 rice ban, are sometimes implemented to safeguard domestic supply. Yet, whereas such interventions can provide temporary relief, excessive or inapt policies might distort markets, discourage private sector investment, and damage long-term competitiveness. Sometimes subsidies and market controls generate inefficiencies that discourage innovation and motivate farmers.

2. Farmer Adaptation

Farmers themselves play a crucial role in managing price risk. They can be encouraged to diversify—planting several crops instead of a sole commodity—to lower exposure to global price variability. Moreover, financial products such as futures contracts and crop insurance provide farmers with the opportunity to hedge against projected loss or price decline. Timely market information, both at a local and global level, enables farmers to make informed decisions about when and where to sell their crops. Mobile technologies and digital platforms are increasingly becoming part of bridging information gaps and enhancing resilience at the farm level. Brown *et.al.* 2008.

3. Investment in Infrastructure

Strategic investment in farm infrastructure has the potential to enhance market performance substantially. Inadequate post-harvest storage frequently results in losses or distress selling at low prices, particularly in rural markets. Enhancing storage facilities, cold chains, and processing units maintains the quality of crops and enables farmers to sell when the prices are better. Additionally, better roads, railways, and port access reduces costs of transport and facilitates smallholders' participation in international markets. Infrastructure not only

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facilitates access to markets but also national competitiveness in agricultural exports.

7.Conclusion and Recommendations

The international agricultural market increasingly influences what local farmers receive and what people pay. Though such interdependence brings new avenues for trade and income, it also makes the local economy vulnerable to price volatility, climate shocks, and changes in external policies. To manage these forces, action and coordination are needed.

Recommendations:

- Implement national crop price monitoring and early warning systems.
- Foster access by farmers to crop insurance and financial hedging instruments.
- Seek out free trade agreements with protection of sensitive agri-food industries.
- Bolster regional trade partnerships in order to minimize dependency on remote markets.

Call to Action

Policymakers, civil society organizations, and farmers will have to collaborate to develop robust agricultural systems that can sustain themselves in the context of a globalized economy. Reading and reacting to world market cues is no longer a choice but a strategic imperative for sustainable development and food security.

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