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AI and Automation in Precision Agriculture

Aswani Kotheri

Strategic and Business Development Team Lead, Think Round, Inc. San Francisco, California. USA

Introduction

Agriculture has always been at the heart of human civilization, providing food and resources necessary for survival. However, with a growing global population, changing climate conditions, and limited natural resources, the traditional methods of farming are facing immense pressure. To address these challenges, the agricultural industry is rapidly embracing Artificial Intelligence (AI) and automation technologies, leading to a new era of precision agriculture. By leveraging machine learning, IoT (Internet of Things) sensors, drones, robotics, and big data analytics, AI-driven solutions are optimizing farm operations, improving crop yields, and promoting sustainable agricultural practices.

The Role of AI in Agriculture

AI is reshaping agriculture in multiple ways, from predictive analytics to automation of farm machinery. Some of the major applications include:

1. **AI-Powered Crop Monitoring and Disease Detection**
   AI-driven image recognition and computer vision systems can analyze satellite imagery and drone-captured data to detect crop diseases, pest infestations, and nutrient deficiencies in real time. Machine learning algorithms process vast datasets to provide early warnings to farmers, allowing for timely intervention and reducing losses. Companies like Taranis and Plantix are using AI-powered image recognition to help farmers detect crop diseases efficiently.
1. **Precision Irrigation and Water Management**
   AI-powered smart irrigation systems use IoT sensors to monitor soil moisture levels and weather conditions. These systems optimize water usage by adjusting irrigation schedules, reducing water wastage, and ensuring efficient water distribution. This technology is crucial in regions facing water scarcity. Companies like

CropX and Jain Irrigation are at the forefront of developing AI-driven irrigation solutions.

2. **Autonomous Farm Machinery**
   AI-driven robots and autonomous tractors are revolutionizing traditional farming by reducing reliance on manual labor. These machines can plant seeds, harvest crops, and spray fertilizers with high precision, leading to increased efficiency and cost savings for farmers. John Deere has introduced See & Spray technology, which uses AI to detect and selectively spray herbicides, reducing chemical usage and costs.
3. **4. Predictive Analytics for Yield Forecasting**
   AI models analyze historical weather patterns, soil conditions, and crop data to predict yields accurately. Farmers can use these insights to make informed decisions on planting schedules, resource allocation, and supply chain management, ultimately enhancing productivity and profitability. IBM Watson Agriculture and AgroScout are using AI-powered analytics to help farmers forecast crop yields more accurately.

Automation in Agriculture: Enhancing Efficiency

Automation is playing a pivotal role in modern agriculture by reducing labor-intensive tasks and increasing operational efficiency. Some key innovations include:

1. **Drones for Crop Surveillance and Spraying**
   Drones equipped with multispectral cameras and AI analytics can map large fields, assess plant health, and even spray pesticides or fertilizers with pinpoint accuracy. This reduces chemical wastage and minimizes environmental impact. DJI Agriculture has developed agribots and drone solutions specifically for precision spraying and crop health monitoring.
2. **Automated Harvesting Robots**
   Labor shortages in agriculture have led to the development of AI-powered robotic harvesters capable of picking fruits and vegetables with minimal human intervention. These robots use sensors and AI algorithms to determine ripeness and harvest crops efficiently. Farming companies like Agrobot and FFRobotics are pioneering the use of automated harvesting solutions.
3. **Blockchain and AI in Supply Chain Management**
   AI and blockchain technology are improving traceability and transparency in the agricultural supply chain. AI analyzes data to detect inefficiencies, while blockchain ensures the integrity of transactions, helping farmers get fair prices and reducing food fraud. Companies such as IBM Food Trust and Ripe.io are working on AI-integrated blockchain solutions for agriculture.

Benefits of AI and Automation in Agriculture

The integration of AI and automation in farming brings several advantages:

- **Higher Productivity:** AI-driven insights help optimize resource allocation, leading to increased crop yields and reduced waste.
- **Sustainability:** Precision agriculture reduces the excessive use of fertilizers, pesticides, and water, promoting environmentally friendly practices.
- **Cost Savings:** Automated processes reduce labor costs and improve operational efficiency, making farming more profitable.
- **Climate Resilience:** AI-driven climate models provide farmers with predictive insights, enabling better preparedness for extreme weather events.

Challenges and Future Prospects

Despite its benefits, AI-driven agriculture faces challenges such as high implementation costs, data privacy concerns, and the need for farmer training. However, advancements in AI, cloud computing, and IoT are expected to make these technologies more accessible to small and medium-scale farmers in the coming years.

Looking ahead, AI and automation will continue to shape the future of agriculture, making food production more efficient, sustainable, and resilient to global challenges. The adoption of smart farming techniques will be crucial in ensuring food security for the growing world population.

Conclusion

AI and automation are revolutionizing agriculture by optimizing farm management, improving resource utilization, and ensuring sustainability. As these technologies become more widespread, they have the potential to transform global food production, making farming more efficient and resilient to climate change. The future of agriculture lies in embracing innovation, and AI-powered solutions from companies like John Deere, IBM Watson Agriculture, DJI Agriculture, CropX, and Taranis will be at the forefront of this transformation.

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Climate-Smart Soil Management Strategies for Sustainable Agriculture

Rajagopal Vadivel

Scientist, National Institute of Abiotic Stress Management, Malegaon Khurd, Baramati Pune, Maharashtra

Agriculture is one of the significant sources of greenhouse gas (GHG) emissions, contributing to climate change through emissions of methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2). Soils play a dual role in the climate system—they can act both as sources of GHGs through various biogeochemical processes and as sinks through carbon sequestration when managed wisely. In India, GHG emissions from agriculture are estimated at around 18–20% of total national emissions, with significant shares from enteric fermentation, rice cultivation, and fertilizer use. Among these, soil-based emissions are a major concern due to intensive tillage, excessive fertilizer use, and poor organic matter management. However, adopting climate-smart soil management practices has the potential to significantly reduce emissions—studies suggest that up to 30–40% of current soil emissions in agriculture can be reversed or mitigated through improved soil health, better nutrient use, reduced tillage, and increased carbon storage. Shifting from conventional to conservation-oriented soil practices can turn soils into effective carbon sinks while also improving crop productivity and resilience.

Introduction

Soil, often regarded as the foundation of agriculture, plays a critical role in the emission and sequestration of greenhouse gases. The complex soil processes such as decomposition of organic matter, nitrification, denitrification, and methanogenesis are closely linked with GHG emissions. Depending on how the soil is managed, it can release substantial quantities of CO_2 (from organic matter decomposition), N_2O (from fertilizer nitrogen transformation), and CH_4 (especially from flooded

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rice fields). These emissions vary significantly based on soil physical properties (texture, structure, porosity, bulk density), chemical properties (pH, cation exchange capacity, base saturation, nutrient content), and biological properties (microbial activity, enzyme functions, organic matter dynamics).

In India, agricultural GHG emissions account for around 485 million tonnes CO_2 equivalent annually, with a major portion arising from soil-based activities. Rice paddies alone contribute nearly 50–55% of total agricultural CH_4 emissions, and N_2O emissions are closely associated with excessive and inefficient nitrogen fertilizer applications. The potential for reducing these emissions through smart soil management is immense. For instance, site-specific nutrient management, organic amendments, crop residue retention, and minimum tillage can reduce N_2O emissions by 25–30%, enhance soil carbon storage by 0.1 to 0.4 tonnes C ha^{-1} $year^{-1}$, and significantly reduce the CH_4 footprint of rice cultivation through water-saving techniques.

This calls for a transition towards climate-smart soil management practices tailored to the diverse agro-ecological zones of India. These practices not only mitigate emissions but also enhance adaptation by improving soil water retention, nutrient cycling, and overall resilience of farming systems.

Climate-Smart Soil Management Practices in Indian Agriculture

1. Conservation Tillage and Reduced Soil Disturbance

Minimum tillage or zero tillage helps maintain soil structure, reduce oxidation of soil organic carbon, and lower CO_2 emissions. In wheat-based systems, zero tillage has shown to reduce fuel use by 40–60% and improve soil carbon stocks, making it a key mitigation strategy in the Indo-Gangetic Plains.

2. Efficient Nutrient Management (4Rs Approach)

Applying the right source of fertilizer at the right rate, right time, and right place can significantly reduce N_2O emissions. Practices such as use of nitrification inhibitors, neem-coated urea, split applications, and precision nutrient tools (like GreenSeeker or Leaf Color Charts) can reduce nitrogen losses and emissions by up to 20–35%.

3. Use of Organic Amendments and Residue Recycling

Incorporating compost, farmyard manure, and green manure enhances microbial activity and soil carbon sequestration. Retaining crop residues rather than burning them can reduce emissions and improve soil fertility. For example, biochar addition has been found to both sequester carbon and reduce N_2O emissions in several Indian soils.

4. Water-Saving Irrigation in Rice Systems (Alternate Wetting and Drying - AWD)

In rice-based systems, AWD and mid-season drainage can reduce CH_4 emissions by 30–70% compared to continuous flooding. This technique also improves water use efficiency and supports better root development, enhancing adaptation to water stress.

5. Diversified Cropping and Agroforestry Systems

Integrating legumes, cover crops, and agroforestry models improves carbon inputs to the soil and biological nitrogen fixation. Tree-based systems can sequester 2–4 tonnes CO_2 ha^{-1} annually while offering co-benefits like fodder, fuelwood, and income diversification.

6. Improved Soil Organic Matter Management

Enhancing soil organic matter through crop rotations, composting, and mulching improves soil aggregation, microbial diversity, and carbon sequestration potential. In India's semi-arid zones, this has led to enhanced soil water retention and yield stabilization under erratic rainfall conditions.

7. Soil Carbon Sequestration through Land Use Change

Shifting degraded or fallow lands into perennial fruit orchards, silvipasture, or agro-horticulture systems has shown significant potential in sequestering carbon. In gravelly lands of the Central Deccan Plateau, such interventions have led to an increase in soil carbon by 0.3–0.6 Mg C ha^{-1} yr^{-1}.

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8. Site-Specific Soil Health Management

Using soil health cards, remote sensing, and decision support systems can guide localized soil amendments and fertilizer use, reducing emissions and input costs. Customized interventions based on soil type, texture, and fertility status are more effective than blanket recommendations.

Cropping System-Based Approaches

Rice-Based Systems

Rice cultivation, especially under flooded conditions, is a major emitter of CH_4 due to anaerobic decomposition. AWD, System of Rice Intensification (SRI), direct-seeded rice (DSR), and integration of organic manures can significantly mitigate emissions. SRI, for example, increases yields while reducing CH_4 by 20–50% and water use by 30–40%. DSR reduces the CH_4 footprint and allows for earlier planting of subsequent crops.

Wheat-Based Systems

Wheat systems benefit from zero tillage, residue management, and balanced fertilization. Retaining rice straw in wheat fields improves soil cover and microbial activity. Zero tillage wheat has demonstrated CO_2 emission reductions of 20–40% and also improves farm profitability. Laser land levelling can further enhance water and nutrient use efficiency, indirectly reducing emissions.

Conservation Agriculture Perspectives for GHG Mitigation

Conservation agriculture (CA), which includes minimum tillage, permanent soil cover, and crop diversification, provides a comprehensive pathway for reducing GHGs from agricultural soils. In Indian conditions, CA-based practices have shown to:

- Reduce N_2O emissions by optimizing fertilizer use
- Decrease CO_2 emissions through carbon stabilization in undisturbed soils
- Lower CH_4 emissions through improved water and residue management in rice
- Increase soil organic carbon stocks, with potential sequestration of 0.2–0.5 tonnes C ha^{-1} yr^{-1}

The integration of CA into mainstream agricultural practices not only curbs emissions but also enhances resilience to climate shocks, reduces erosion, and improves biodiversity. Its scalability in India is promising, especially in regions like the Indo-Gangetic Plains, Central India, and parts of the Western Ghats.

Conclusion

Climate-smart soil management holds immense potential to reduce agricultural greenhouse gas emissions while simultaneously enhancing productivity, soil health, and resilience. Adoption of practices such as zero tillage, AWD in rice, balanced fertilization, residue retention, organic amendments, and agroforestry can cumulatively reduce soil-based emissions by 30–40%, depending on the cropping system and local conditions. To popularize these practices among farmers, several policy interventions are essential:

- Incentivize low-emission farming practices through carbon credits, subsidies, and recognition programs.
- Promote farmer training and awareness on soil health and GHG emissions using digital platforms and extension services.
- Expand soil testing and soil health card schemes with actionable recommendations on climate-smart inputs.
- Support community-based resource management, especially in regions vulnerable to climate change.
- Invest in research and demonstration of region-specific CA and soil management technologies.

Ultimately, transforming India's soils from a source to a sink of greenhouse gases requires a collaborative effort—between farmers, scientists, policymakers, and civil society. Smart soil management is not only climate action but also a pathway to resilient, productive, and sustainable agriculture.

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Nanotechnology – A need for sustainable agriculture

Aranav Yadav[1*], Pradeep Kumar[2], Ravi Pratap[3]

[1]Department of Genetics and Plant Breeding, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur – 2080 02, Uttar Pradesh, India

[2,3]Department of Fruit Science, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur – 2080 02, Uttar Pradesh, India

Food consumption is expected to climb from 59 to 98 percent by 2050 when the global population reaches 9.7 billion people. To boost food security, newer technology is required that will increase production while reducing food waste. Nanotechnology plays a significant role in all aspects of agriculture in order to ensure sustainability. These cover: agronomy, genetics, plant breeding, entomology, plant pathology, seed technology, plant physiology, soil science, agricultural engineering, veterinary science and fisheries science. It also helps with food processing, food modification, stability, sensing, shelf life extension, food loss reduction, and food safety. It has the potential to boost crop yield by providing effective microbial, insect, and weed control that is high in economic value, security, and safety.

According to the United Nations Food and Agriculture Organization (FAO), about one-third of the world's population, or 2.37 billion people, lack adequate food. The world's future issues include climate change, population expansion, and land degradation. Food consumption is expected to climb from 59 to 98 percent by 2050 when the global population reaches 9.7 billion people. To boost food security, newer technology is required that will increase production while reducing food waste. Agricultural efficiency, soil improvement, secure water use, food distribution in shops, and food quality are all basic aspects of food security that nanotechnology research can improve.

Nanotechnologies are technologies with at least 50% natural or artificial particles in the size range of 1 to 100 nanometers (up to a billionth of a meter). Nanotechnology thanks its potential to the unique properties of nanoparticles (e.g. high volume to surface ratio and high solubility) therefore; nanoparticles show an increased reactivity and efficiency.

POTENTIAL OF NANOTECHNOLOGY

Nanotechnology has recently been proven to have the ability to improve the agriculture sector by increasing the efficiency of agricultural inputs and bringing solutions to agricultural challenges, resulting in increased food productivity and security. Nanotechnology plays a significant role in all aspects of agriculture in order to ensure sustainability. These cover: seedlings showed a 90 percent increase in drought resistance after being treated with nanoparticles. A 16.5 percent improvement in seed life was also seen after storage. These benefits help to improve yield quality and quantity, as well as climate resistance. The goal of nanoparticles is to reduce chemical dissemination, reduce nutrient loss during fertilization, and improve quality and production by using the right nutrients. Currently, research is being conducted to develop nano-composites that will give all of the vital nutrients in the proper proportions using a smart delivery system. Nano-hydrogel can be used to make agricultural output more sustainable and to improve water consumption. It may absorb and release water and nutrients in cycles, making water use more effective. The encapsulated nano-herbicides are important because they address the demand for a nano-herbicide that is protected in the natural environment and only functions when there is a period of rainfall. Nanotechnology has the potential to improve pesticides by reducing toxicity, expanding shelf life, and enhancing the solubility of pesticides that are poorly water soluble, all of which could have a positive environmental impact. Nanotechnology also aided gene sequencing, which increased the identification and application of plant trait ways, adjusting their ability to adapt to environmental stresses and illnesses. Quantum dots and nanoparticles have proven to be an extremely accurate biological marker. More than 40% of food losses in wealthy countries (cereals, roots and tubers, pulses and oil crops, vegetables and fruit, fish meat, and dairy) occur at the trade and customer phases, whereas more than 40% of food losses in developing countries occur at the post-harvest stage and processing point. By creating functional packing elements with the least amount of bioactive constituents, enhanced gas and mechanical capabilities, and a minimized effect on sensor quality of vegetables and fruits, nanotechnology can reduce post-harvest losses. Nanotechnology is gaining traction in industrial food processing, and novel technologies are needed in the food industry to improve production, market price, and quality. Plentiful uses of nanotechnology regarding food production and processing are developed including nano based food additives, nano-encapsulation, nano-sensors and nanoparticles based smart distribution systems. In the subject of agricultural machinery, nanotechnology has numerous uses. These include applications in machine structures and agricultural tools to increase their resistance to wear, corrosion, and ultraviolet rays; manufacturing strong mechanical components using nano-coatings and bio-sensors in smart machines for mechanical-chemical weed control; and manufacturing nano-covers for bearings to reduce friction. It's also worth highlighting the application of nanotechnology in the development of alternative fuels and the reduction of pollution. Nanotechnology has the potential to give acceptable solutions for veterinary care, prescription drugs, and domesticated animal immunizations. Taking certain medications such as antibiotics, vaccines, and probiotics, would be effective in treating the infections, nutrition and metabolic disorders, when used at the nano level. Nanotechnology has the ability to completely transform the fisheries and aquaculture industries. Nanotechnology techniques such as nanomaterials, nanosensors, DNA nanovaccines, gene delivery, and smart medication delivery have the ability to solve a wide range of problems in fisheries nutrition and health production, reproduction, illness prevention, and treatment. By detecting germs in packaging, providing strong flavor, color quality, and safety, nanotechnology will aid the fish processing industry in manufacturing high-quality products. Nanotechnology's implementation in agricultural production offers the potential to reduce pollution caused by fertilizers and heavy metals. Because of their uncontrolled application, up to 90% of agrochemicals end up in the environment. Pollution is reduced as a result of enhanced efficiency and smart delivery systems and so environmental and health hazards are reduced.

CONCLUSION

Nanotechnology is essential for establishing food security, particularly in agriculture. It has the potential to boost crop yield by providing effective microbial, insect, and weed control that is high in economic value, security, and safety. It also helps with food processing, food modification, stability, sensing, shelf life extension, food loss reduction, and food safety. However, much more research is needed in this field before it can be widely embraced by ordinary people without damaging Mother Earth's ecology.

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Water Security: A way to manage water resources sustainably through natural infrastructure

Shatruhan Jaiswal and Abhishek Kumar Singh

Ph.D Research Scholar and M.Tech. Scholar, Dept. of SWCE, CAEPHT, Gangtok, Sikkim
(Central Agricultural University Imphal, Manipur)

Introduction

The concept of water security has received increased consideration over the past decade, in both policy and academic debates. Over the past ten years, it has also gained prominence on several domestic water management agendas, especially those related to (bio-)terrorism concerns. As a result, some have described it as "a key objective of a range of governmental and nongovernmental agencies across the spectrum of governance levels." (Jansky *et al.,* 2008). There are top most-cited articles as containing the term "water security" in the Web of Science database (including both social science and natural science journals) is based in a different discipline. In descending order of citation frequency, the articles are from fisheries science, hydrology, public health, environmental studies, and water management/ policy (Ashton, 2002; Do¨ ll *et al.,* 2003; Hrudey *et al.,* 2003; Schindler, 2001; Shuval, 1992). It is estimated that, 380 billion m^3 of wastewater is produced globally each year, a figure projected to increase 24% by 2030 and 51% by 2050 EIB., (2022). Water deterioration has become a global concern due to increase in the human population and economic activities. (Biswas & Tortajada, 2019). According to UNICEF 2021, 1.42 billion people reside in places that are extremely vulnerable to water. Therefore, the extreme threat to world prosperity is the water crisis, which is Nigeria is among the African nations with water security issues (Adejumo, 2020).

Keeping in above views, the natural infrastructure which includes ecosystems such as wetlands, forests,

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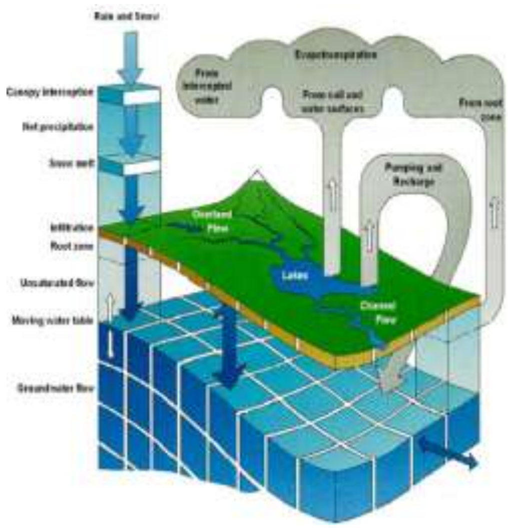
grasslands, and vegetated watersheds, that improve water quality and reduced droughts and floods. These ecosystem supports the hydrological cycle by regulating precipitation patterns, increasing groundwater recharge, reducing runoff and improving water quality. Proceedings of the National Academy of Sciences, natural ecosystems have the ability to augment water security through regulation of the timing, amount, and quality of water flow by means of infiltration, interception and evapotranspiration, as documented (Brauman *et al.,* 2008). In addition, the incorporation of natural infrastructure along with traditional means enhances climate resilience and decreases risks of disasters which has asserts in its "Nature-based Solutions for Water" UNEP report (2018). The same method, which identifies reducing costs and enhancing the performance of water infrastructure systems, particularly in flood-prone or water-scarce areas World Bank report (2019).

Fig.1. A typology guide to understanding water security

Source: https://www.researchgate.net/publication/324561662

This growing realization of the shortfalls of traditional grey infrastructure has resulted in a shift in paradigm in managing water resources. Scientists, policymakers, and environmentalists are now calling for the incorporation of nature-based solutions as complementary approaches to long-term water resilience. Natural infrastructure presents an adaptive and dynamic means of acting in conjunction with, as opposed to counter to, natural forces. By understanding and capitalizing on the ecosystem services that forests, wetlands and vegetated landscapes offer can design systems that are both more sustainable and cost-effective, and more climate-resilient than relying on traditional engineering alone. this article is to examine the scientific principles and practical advantages of how natural infrastructure delivers water security through primary natural processes like evapotranspiration, interception, infiltration, and soil stabilization, underpinned by empirical research and real-world case studies. The only hydrological processes which may be carried out by these ecosystems to solve both water shortage and excess and may be provide a clean and adequate water across a range of temporal and spatial scales.

Fig.2. A simple way towards water security



(a)

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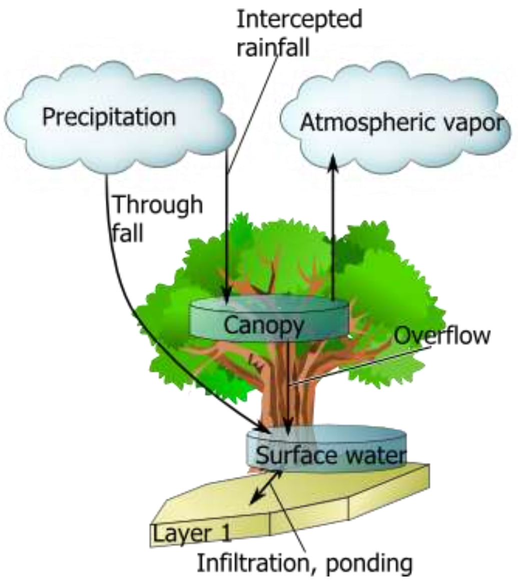
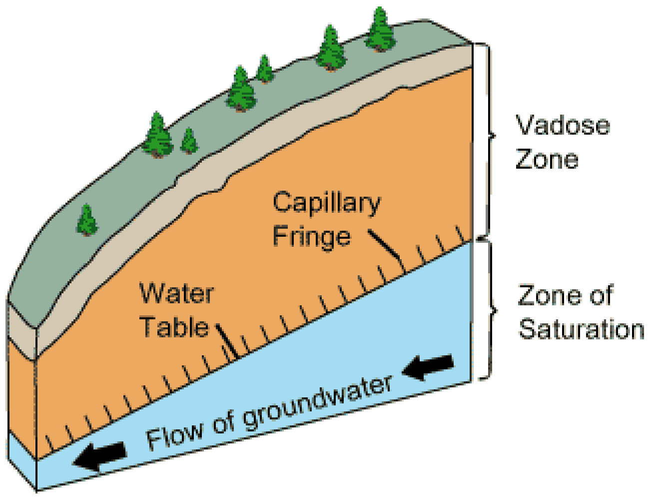


(b)



(c)

Fig.3. (a, b & c) Conceptual view of water cycle, Interception process & Infiltration Process

Source:https://www.researchgate.net/publication/265539232,https://philippkraft.github.io/cmf/cmf_tut_intercept.html & https://en.m.wikipedia.org/wiki/Infiltration_(hydrology)

Evapotranspiration

Evapotranspiration is the process in which water transpired by vegetation and evaporated from soil and surface water bodies. This process involves in the regulation of local and regional precipitation patterns and climate stability. This process begins as the roots extract water from soil. This water goes different parts of plants through xylem tissues. At last, water escapes through stomatal openings as vapour.

When trees draw water from the soil and emit it as vapor through their leaves, they form microclimates that can add as much as 70% to atmospheric moisture in heavily forested areas. This "flying river" phenomenon is especially visible in rainforests such as the Amazon, where about 50-80% of rainfall is cycled back into the atmosphere by evapotranspiration, supporting precipitation thousands of kilometers away.

Interception

Forest canopies serves as natural's umbrella. Initially when precipitation starts, it falls on the forests. Multilayered vegetation reduces velocity and impact on the soil, allowing better absorption and minimizing surface runoff. Canopy interception during intense rainfall events can minimize the immediate effect of precipitation by 15-30%, stopping flash flooding and soil erosion. The gradual release of intercepted water enables soil to absorb moisture, rather than becoming saturated. In mountainous terrain, this buffer can be the difference between flash floods that devastate and manageable water flow.

Infiltration

Tree roots and organic matter that has broken down enhance porosity in the soil, allowing water to infiltrate into deeper layers and recharge aquifers. This not only maintains groundwater levels but also helps to buffer against seasonal water shortages. The combination of organic material and biological activity in forest soils also acts as a natural filtration system, improving water quality as it moves downward.

Soil Stabilization

The complex system of tree roots mechanically holds soil particles in place, preventing sedimentation and keeping watershed integrity intact. This stabilization of the soil becomes especially important on slopes and riparian areas where erosion potential is greatest. In slopes, root systems in forests lower soil erosion by 75-95% from bare ground. This not only saves soil fertility but also keeps sediments from filling up watercourses that otherwise damage aquatic environments, lower reservoir levels, and escalate water treatment expenditures. Root binding goes beyond mechanical stability to establish soil forms that maximize water holding capacity and control of flow.

Impacts & Implications on Water Security through Evapotranspiration, Interception and Infiltration:

- Regulates rain patterns and sustains regional rain (e.g., Amazon rainforest is responsible for more than half of its own rainfall).
- Assists in cooling the atmosphere, impacting climate and water demand.
- In arid areas, preserving vegetative land cover increases atmospheric moisture and stabilizes rains.
- Decreases soil erosion by avoiding splash erosion.
- Slows down water supply to the soil, increasing infiltration rates.
- Avoids sudden stormwater surges, reducing flood risks.
- Improves groundwater recharge, essential for drinking water, irrigation, and baseflow maintenance in rivers.
- Lessens surface runoff, reducing flood potential.
- Encourages aquifer sustainability, particularly important in arid areas.
- Prevents loss of fertile topsoil, essential for agriculture.
- Reduces sedimentation in reservoirs, canals, and irrigation systems—reducing maintenance costs.
- Preserves watershed integrity and river flow quality.

Conclusion

Water security has emerged as a critical global concern driven by population growth, economic activity and climate change. Traditional grey infrastructure alone is insufficient to meet these challenges sustainably. Natural infrastructure such as forests, wetlands and vegetated watersheds have offers a cost-effective, resilient and ecologically sound alternative. Through natural hydrological processes like evapotranspiration, interception, infiltration, and soil stabilization ecosystems enhance water availability, regulate climate, reduce floods and droughts and simultaneously improve the water quality. Integrating nature-based solutions with conventional systems provides a balanced approach to ensuring long-term water security, fostering ecological health and supporting livelihoods across diverse geographies. Mixing nature-based solutions with grey infrastructure is internationally accepted as best practice today. As noted by the UNEP's "Nature-Based Solutions for Water" (2018) and the World Bank's "Integrating Green and Gray" (2019) report, these strategies have the potential to increase climate resilience, lower infrastructure expenditures, and provide sustainable water availability for people and ecosystems in the long term.

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Can Plants hear? - Plant acoustics responses

Anusree K. and Simhi Samyuktha S.M.

1PhD Scholar, Kerala Agricultural University

Sound is a mechanical pressure wave sensed by many organisms, including plants, despite their lack of specialized hearing organs. Phytoacoustics, an emerging field, studies how plants perceive and respond to sound vibrations. Historical experiments by pioneers like Jagadish Chandra Bose and recent studies show that plants can respond to acoustic cues such as pollinator wingbeats or herbivore chewing vibrations. These sounds can trigger physiological changes like increased nectar production or chemical defenses such as glucosinolates and anthocyanins. Specific sound frequencies have also been shown to enhance phytochemical contents like flavonoids by upregulating key biosynthetic genes. Mechanistically, sound vibrations activate mechanosensitive ion channels in plant membranes, particularly MSL and MCA proteins, leading to calcium (Ca^{2+}) signaling, reactive oxygen species (ROS) production, and hormonal changes including ethylene modulation. This cascade influences gene expression and contributes to growth, defense, and development. However, responses vary by species and sound frequency, and the scientific community remains divided due to inconsistent results and a limited understanding of the underlying mechanisms. Despite challenges, phytoacoustics holds potential for innovative, sustainable agricultural practices. With deeper insights into how sound shapes plant physiology and ecology, targeted sound treatments may enhance crop yield, quality, and stress resilience without chemical inputs.

Introduction

Sound is a mechanical wave of pressure that requires a transmission medium to propagate. Hertz and decibel measurements are commonly used to determine its frequency and strength. To assess their environment and communicate, highly evolved organisms like humans and other animals are born with specialised sound generating and catching mechanosensory systems. The fact that various creatures emit and pick up on particular noises within their auditory frequency range is an intriguing biological phenomenon.

According to how people perceive sound, it can be divided into three categories: audible or sonic (20 Hz–20 kHz), infrasonic (< 20Hz) and ultrasonic frequencies (> 20 kHz). This could be primarily attributed to the varying sensitivity to a particular sound frequency and acoustic organ motions that provide diverse living forms their own modes of communication. Although plants do not possess specialized organs, neural networks, or a brain like animals, they are still capable of perceiving their environment, gathering essential information through different mechanisms, and making adaptive decisions accordingly. Plant perception or cellular biocommunication suggests that plants are sentient beings capable of experiencing sensations like pain, pleasure, or emotions such as fear and affection, and that they can interact with humans and other life forms in ways that are understandable. Although plants do exhibit communication through chemical signaling and display intricate responses to various stimuli, the notion that they possess higher emotional or cognitive capacities is not widely supported within mainstream scientific circles.

Bioacoustics is the scientific study of sound production, transmission, reception, and the role of sound in the behaviour, communication, and ecology of animals and plants, as well as its applications in various fields such as wildlife biology and environmental conservation. Phyto acoustics is an emerging scientific field that focuses on the study of sounds produced and perceived by plants. It involves the exploration of the acoustic emissions, vibrations, and other sound-related phenomena generated by various plant structures and processes, with the aim of understanding their significance in plant biology, ecology, and interactions with the environment.

Sound sensing at the cellular level -Sound vibrations can activate MSL (Mechanosensitive-Like) channels in plants, initiating a signaling cascade based on changes in membrane potential. Stretch-activated channels are believed to play a key role in this sound-induced signaling. So far, two types of such channels have been discovered in plants: MSLs, which are non-selective ion channels, and Mid1-complementing activity (MCA) proteins, which function specifically as calcium (Ca^{2+}) channels. The main site of their action is the plasma membrane (PM), which, when disturbed by sound vibrations, triggers a sequence of signaling events that lead to a physiological response.

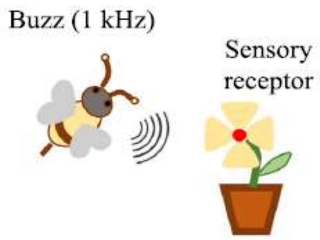
Among the potential molecular mediators of sound vibration signals, calcium ions (Ca^{2+}) appear to be the most promising secondary messengers. MSL and MCA proteins, both located in the plasma membrane, are thought to mediate the influx or efflux of Ca^{2+} in response to sound waves. This leads to the formation of transient spikes in intracellular calcium concentration, which are crucial for sound-associated signaling. These calcium signals are likely detected by various Ca^{2+}-binding proteins or calcium-dependent protein kinases (CDPKs), which relay the information via phosphorylation or dephosphorylation events to downstream signaling molecules or transcription factors, eventually leading to the activation of specific genes.

Proline and reactive oxygen species (ROS), which are produced in greater amounts in cells exposed to sound vibrations, collectively contribute to the enhanced activation of calcium (Ca^{2+}) channels as well as potassium (K^{+}) channels. Additionally, sound-treated cells exhibit elevated α-amylase activity, resulting in increased sugar content. The combined action of Ca^{2+}, ROS, and sugars can trigger distinct signaling pathways that promote upregulation of gene expression.Hormones such as auxin and ethylene, which are involved in sound-induced responses, are believed to directly influence specific transcription factors—auxin response factors (ARFs) and ethylene response factors (ERFs), respectively—thus modulating gene activity. Multiple gene/protein groups are differentially expressed or activated in response to sound stimuli in plant cells. The energy driving these processes is supplied by ATP, which is produced at higher levels in cells sensitized by sound.Among the central components of plant signal transduction mechanisms is intracellular Ca^{2+}, often referred to as a second messenger. This ion diffuses quickly to transmit signals from external cues to intracellular target proteins, such as enzymes. When a sound stimulus is perceived, cytoplasmic Ca^{2+} levels rise briefly—known as Ca^{2+} transients—initiating a cascade of signaling events that lead to physiological responses.

Another key element in these signaling networks is protein kinases. These enzymes phosphorylate target proteins, including transcription factors, thereby directly influencing gene expression (Choi *et al.*, 2005). Research indicates that sound-stimulated cells show increased protein kinase activity. Therefore, it is proposed that sound-induced activation of protein kinases leads to phosphorylation of signaling molecules and/or transcription factors, ultimately resulting in the upregulation of specific genes.

Responses of plants towards sound vibrations

Gagliano *et al.* (2017) investigated how *Pisum sativum* roots detect and locate water, focusing on the role of acoustic cues. Using a custom Y-maze, they tested whether roots respond to the sound of water. In Experiment 1, 8/10 seedlings grew toward water a nd similarly toward the sound of water in sealed pipes, even without direct moisture. Experiment 2 used sound recordings and found roots avoided white noise (8/10) and silent equipment (9/10), suggesting a response not only to sound but possibly to other cues like magnetic fields. Experiment 3 explored co-occurring cues; when both moisture and recorded water sounds were present, roots preferred moisture (8/10). When water sound recordings competed with other sounds, root behavior varied, indicating acoustic cues influence root orientation but are secondary to moisture. Results suggest roots can detect vibrations through mechanosensitive channels and integrate multiple signals like sound, moisture, and magnetism. Interestingly, roots often avoided the side with sound equipment, even when no sound was emitted, possibly due to magnetotropism. These findings suggest plants can use sound to broadly locate water, but rely on moisture cues for accurate direction. This study opens new insights into plant behavior and sensory capabilities.



Veits *et al.* (2019) explored whether flowers can detect pollinator sounds and respond by increasing nectar sugar concentration to enhance pollination. Using *Oenothera drummondii*, pollinated mainly by bees and moths, they tested how flowers respond to different sound treatments. Experiments involved exposing flowers to natural bee sounds, low-frequency sounds (50–1000 Hz), high-freque ncy sounds (158–160 kHz), intermediate frequencies (34–35 kHz), and silence. Results

showed that flowers exposed to bee sounds or low-frequency signals increased nectar sugar concentration significantly—by 1.2 times—compared to those exposed to high-frequency sounds or silence. Flowers did not respond when enclosed in glass, suggesting that the flower itself acts as the plant's "ear," vibrating in response to airborne sounds within pollinator wingbeat frequencies. The response was frequency-specific; flowers did not vibrate or react to intermediate or high frequencies. This suggests that plants may use flower vibrations as a sensory mechanism to detect pollinators and enhance rewards at optimal times, improving pollination efficiency. The mechanical properties of flowers—such as size and shape—may have evolved under selection pressure to resonate with the sound frequencies of their pollinators. This study reveals a new sensory role of flowers in plant–pollinator communication.

Appel *et al.* (2014) demonstrated that plants can detect chewing vibrations caused by herbivorous insects and activate chemical defenses in response. Using *Arabidopsis thaliana*, they exposed leaves to recorded caterpillar (*Pieris rapae*) feeding vibrations and then allowed real caterpillars to feed on the plants. Results showed a significant increase in defensive compounds—aliphatic glucosinolates and anthocyanins—in leaves pre-exposed to chewing vibrations compared to control treatments (wind, leafhopper song, or silence). The response was both local and systemic, with glucosinolates increasing by 32% in the vibrated leaf and 24% in a same-age systemic leaf. No response was observed in younger, unexpanded leaves.

Anthocyanin levels also rose significantly only in plants exposed to chewing vibrations, not to other vibration types, indicating specificity. The study suggests that vibrations may trigger defense via direct propagation through plant tissues or through systemic signaling, potentially involving airborne volatiles or electrical signals. Mechanistically, vibrations may activate mechanosensors, leading to calcium fluxes, reactive oxygen species (ROS), and hormonal changes involving jasmonates and ethylene. These early signaling events initiate defense gene expression. This study highlights the ecological importance of vibrational cues in plant defense and suggests plants can "hear" herbivore activity and prime themselves for attack.

Sound vibrations can influence plant hormone levels and delay physiological processes like fruit ripening. Ethylene, a key hormone in fruit ripening, is particularly affected. Bochu *et al.* (2004) found that sound waves (1.4 kHz, 95 dB) increased indole acetic acid (IAA) and decreased abscisic acid (ABA) in *Chrysanthemum*. Kim *et al.* (2015) explored the impact of sound waves on tomato ripening and found that 1 kHz sound treatment delayed ripening, reduced ethylene production, and maintained fruit firmness. Tomatoes treated with 1 kHz sound waves ripened more slowly than controls, with lower respiration rates and delayed color change from green to red. Molecular analysis showed that key ethylene biosynthesis genes—*LeACS2*, *LeACS4*, and *LeACO1*—had reduced expression in sound-treated fruit. Ethylene-inducible genes *E4* and *E8* were also downregulated. The most significant changes in gene expression occurred between 5–7 days after treatment. These results suggest that sound waves modulate membrane properties and gene expression, thereby delaying ethylene production and fruit ripening. This demonstrates that sound waves act as external stimuli affecting hormone regulation and extending fruit shelf life by slowing down senescence.

Sound vibrations can enhance the production of functional metabolites like flavonoids by regulating gene expression. Kim *et al.* (2021) exposed red radish, lettuce, and Chinese cabbage sprouts to different sound wave frequencies (0.25–1.5 kHz) and found that specific treatments increased total flavonoid content. This was linked to upregulation of key genes in the flavonoid biosynthesis pathway, including *PAL*, *C4H*, *CHS*, *CHI*, *DFR*, and *ANR*. The 1-kHz ST5 and 0.25-kHz LT3 treatments notably boosted flavonoids in red radish. However, responses varied by species and treatment type, suggesting sound waves can selectively modulate antioxidant metabolite synthesis in plants.

Conclusion

Plants perceive a limited range of natural sound frequencies, and artificial sound exposure may disrupt this communication, potentially interfering with pollination, defense, and orientation cues. High-intensity sounds can suppress natural ones, affecting ecological balance by disturbing other plants, beneficial insects, and microbes. Research on sound's effects on plants shows mixed results due to species-specific responses and methodological inconsistencies. Identifying optimal sound treatments for individual crops remains a challenge. While sound may enhance growth alongside primary factors like nutrition and water, its long-term impact and underlying mechanisms require deeper molecular and physiological study for practical use in sustainable agriculture.

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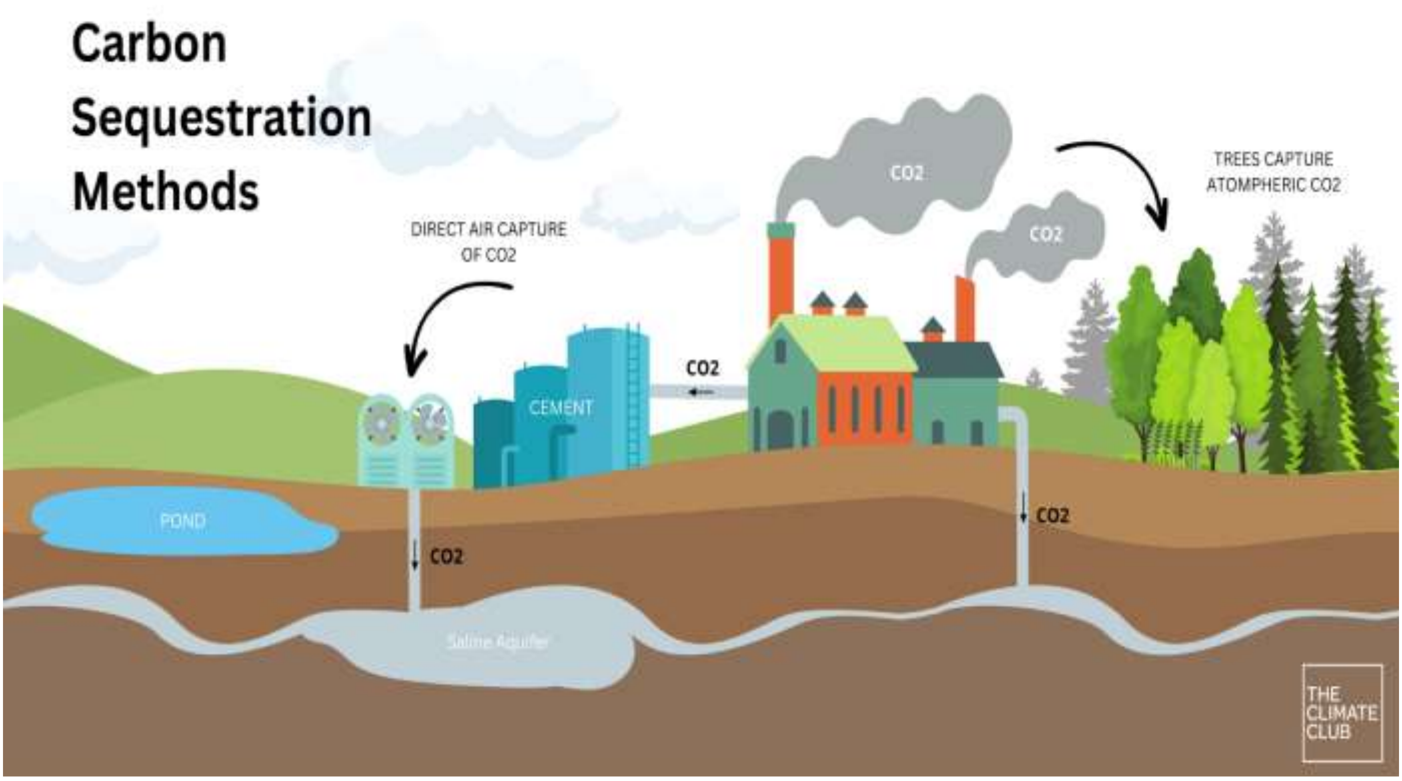

Role of Agricultural Engineering in Soil Conservation and Carbon Sequestration

Suyog Balasaheb Khose[1], Madhukar Rao More[2] and Shashi Bhushan Kumar[1]

[1]PhD Scholar, Indian Institute of Technology Kharagpur (West Bengal)

[2]Professor (CAS), Department of SWCE, VNMKV Parbhani-431 402 (M.S.)

The term "soil" refers to more than just the dirt we walk on; it is the very foundation of human civilization and a critical source of nutrients essential for agriculture. Soil plays a fundamental role in food production, environmental health, and the overall functioning of the global economy. Remarkably, nearly 95% of the food we consume originates from the soil, underscoring its vital role in sustaining life. Healthy soils, rich in nutrients and organic matter, ensure that plants grow strong, resilient, and highly productive. Beyond supporting crops, soil acts as a natural water reservoir and filtration system, enhancing clean water availability and promoting the sustainability of agricultural practices.

Moreover, soil serves as a habitat for a vast array of microorganisms, insects, and fungi, all of which contribute to its fertility and long-term productivity. However, this invaluable resource is under constant threat from erosion, nutrient depletion, contamination, and overexploitation. Today, soil degradation affects nearly one-third of the Earth's fertile land, leading to diminished agricultural yields and increasing food insecurity. The economic impact is staggering, with trillions of dollars lost annually due to reduced productivity and ecosystem services.

Given these alarming trends, conserving soil has become more critical than ever. Addressing the challenges of soil degradation calls for heightened awareness, the adoption of sustainable farming practices, and the integration of technological innovation areas where agricultural engineering plays a pivotal role. By blending science with technology, agricultural engineering offers practical, sustainable solutions for soil conservation and long-term land productivity, ensuring food security and environmental balance for generations to come.

1. Soil and Water Conservation: One of the most significant contributions of sustainable agricultural practices is effective erosion control. Techniques such as terracing, contour farming, and the use of vegetative buffer zones play a crucial role in preventing the loss of fertile topsoil, particularly in hilly or sloped regions. In addition to these, conservation tillage practices like "no-till farming" not only help maintain soil structure but also contribute to reducing carbon emissions, enhancing water retention, and promoting biodiversity. Together, these methods support long-term soil health and agricultural productivity, while also contributing to broader environmental sustainability.

2. Irrigation and Drainage: Agricultural engineers play a vital role in optimizing water use to sustain soil health and promote efficient farming. Through the development of advanced irrigation systems like drip and sprinkler irrigation, water is delivered directly to the root zones of crops, reducing wastage and preventing issues such as waterlogging and soil salinization. These modern systems are increasingly integrated with soil moisture sensors and automated technologies that provide real-time data, enabling precise water application and minimizing overuse. Additionally, precision agriculture tools enhance soil health by enabling the targeted application of fertilizers and other inputs, reducing nutrient runoff and supporting environmentally sustainable farming practices.

3. Soil restoration: Reforestation, controlled grazing, and bioengineering are effective methods for restoring degraded land by enhancing soil organic matter and nutrient content. Engineers support these efforts by developing machines for composting and incorporating organic material into the soil, promoting the use of natural resources to rejuvenate depleted lands. Agricultural engineers blend modern innovations with traditional practices to design sustainable systems that restore soil health while maintaining agricultural productivity, ensuring a balanced approach to environmental conservation and food security.

4. Carbon Sequestration in soil: Climate change is increasingly becoming a major threat to agriculture, particularly in dryland regions. Unpredictable rainfall patterns, sudden high-intensity downpours, and declining soil fertility are significantly undermining the productivity of these areas. To combat this, reducing greenhouse gas emissions through enhanced carbon fixation in soil and vegetation is essential. Both agriculture and forestry offer vast potential for carbon sequestration. In particular, soil organic carbon plays a vital role in the cycling of essential nutrients, while also improving the soil's biological, physical, and chemical properties. It helps prevent degradation, reduces erosion, enhances moisture retention, and supports overall soil health. As a result, improving soil carbon not only boosts agricultural productivity but also contributes to long-term environmental sustainability.

Increasing the amount of organic carbon in the soil is a gradual process, particularly in tropical regions, were rapid decomposition of organic matter limits long-term carbon retention. This challenge is compounded by rising atmospheric carbon levels carbon dioxide concentrations, for example, have increased from 280 ppm in 1950 to 391 ppm by 2012. Additionally, levels of methane and nitrous oxide have also risen significantly. These greenhouse gases contribute to global climate change, which is causing noticeable shifts in precipitation patterns, rising sea levels, more frequent extreme weather events, and an increase in storm intensity. These changes are having serious impacts on ecosystems and communities, especially in vulnerable tropical regions.

The contribution of organic carbon in soil organic matter to plant growth is largely determined by its biological, physical, and chemical properties. Organic carbon helps bind soil particles, enhancing soil structure and fertility. Remarkably, soil has the capacity to store two to four times more carbon than the atmosphere, playing a vital role in mitigating carbon dioxide emissions. Soil organic carbon (SOC) is primarily derived from decomposed plant and animal residues, while soil inorganic carbon (SIC) consists of carbonates and elemental carbon. There is significant potential to increase inorganic carbon storage through secondary carbonate formation in both trees and soil. Additionally, bio-carbonate transport from irrigated lands using high-quality water presents another opportunity. However, the rate of secondary carbonate formation remains very low, estimated at only 5 to 10 mg per hectare per year highlighting the need for long-term strategies to enhance carbon sequestration in soils.

Rising temperatures in Indian soil have contributed to a decline in organic carbon content, which is now often less than 5 milligrams per kilogram. However, land management practices such as reduced tillage, balanced fertilizer use, efficient irrigation, and effective residue management can help increase the organic carbon levels in the soil. Minimizing the intensity and frequency of tillage and retaining crop residues on the land are particularly effective in enhancing soil carbon content. Increasing carbon sequestration in soil offers multiple benefits: it improves soil structure, supports environmental balance, and helps mitigate the negative impacts of rising carbon dioxide emissions. Higher levels of organic carbon enhance the soil’s ability to supply nutrients, improve its physical properties, and promote microbial activity, which in turn supports healthy crop growth. Additionally, improved organic carbon levels increase the soil's water retention and permeability, boosting its capacity to store and deliver water efficiently to crops.

The 1997 Protocol to the United Nations Framework Convention on Climate Change is regarded as a pivotal step toward addressing climate change, primarily by targeting the reduction of greenhouse gas emissions and enhancing carbon sequestration. Failure to curb these emissions could have severe consequences for humanity. A recent report by the Intergovernmental Panel on Climate Change (IPCC) has warned that over three billion people worldwide may suffer the impacts of climate change. According to the report titled Climate Change 2022: Impacts, Adaptation, and Food Security, continued high levels of carbon emissions could result in heat and humidity levels surpassing human tolerance thresholds.

India is among the countries projected to experience these intolerable climate conditions. The report highlights that climate change will significantly affect agriculture and food production across the Asian continent. Specifically, India may see a decline in the productivity of major crops like rice and maize. Additionally, a growing gap between water supply and demand could lead to widespread water scarcity across Asian nations. The report further cautions that if current trends continue, rising temperatures may increase the frequency and severity of droughts in Asia by 5 to 20 per cent by the end of this century.

In light of these alarming projections, it becomes increasingly evident that soil conservation is not merely an environmental concern but also an economic and social imperative. Without healthy soils, food security, water availability, and climate resilience are at serious risk. This underscores the critical role of Agricultural Engineering and the responsibility of agricultural engineers in developing and implementing sustainable soil management practices and technological innovations. Healthy soils form the foundation of a thriving planet, and their protection is a collective responsibility that we must uphold for the well-being of future generations.

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Major Insect Pests of black gram and their Management in Bundelkhand Region

Kuldeep Meena, Pradeep Kumar, Abhishek Kumar Chaudhary and Saurabh Singh
Institute of Agricultural Sciences, Bundelkhand University Jhansi 284128, Uttar Pradesh

India is a significant pulse-growing nation that accounts for 28% of the world's pulse basket from an area of roughly 37%. following cereal. They have unquestionably been regarded as the poor man's meat for those in need who cannot purchase animal protein. Black gram is a rich source of protein (20.8 to 30.5%), 3.2% minerals, and carbohydrates (56.5 to 63.7%). It is scientifically known as *Vigna mungo* L and commonly known as urd-bean in India. Its primary origin is India (Ali and Gupta, 2012). Black gram contributes about 10% in national pulse production. and is the fourth most significant short-duration pulse crop in India. Additionally, each 100g of split dual contains 38 mg of β-carotine, 9.1 mg of iron, and 154 mg of calcium. Andhra Pradesh, Assam, Bihar, Gujarat, Haryana, Maharashtra, Karnataka, Kerala, Tamil Nadu, Madhya Pradesh, Rajasthan, Uttar Pradesh, West Bengal, and Tripura are the major Indian states that grow black gram. It is typically grown as a kharif crop in the majority of the country. At the national level, urd-bean's area, production, and productivity are 32.15 lac ha, 17.66 lac tonnes, and 549 kg/ha, respectively. The annual yield loss due to the insect pests has been estimated at about 30 per cent in black gram and mung bean (Gailce Leo Justin *et al.*, 2015). The poor productivity of the crop in jhansi district has been attributed to many factors but among them insect pest infestation is a major limiting factor. The present research article to described their effects of abiotic and biotic stress influenced the infestation and stabilization of various insect pests in black gram and their integrated based management.

Major Insect Pests of black gram

Spotted pod borer (*Maruca vitrata*)

Taxonomy- This legume flower and pod borer are scientifically known as *Maruca vitrata* Fabricius, but

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it is also known as *Maruca testulalis* Geyer and *Croshipora testulalis* Geyer. It is a member of the Crambidae family and order Lepidoptera which is formally classified as Pyralidae and has only one L seta on its ninth abdominal segment.

B. Host range- Cowpea, pigeonpea, black gram, green gram, rice, and soybean all are serious pests in India. Although hostplants are sparse during the off-season, it survives on alternate hosts such as wild leguminous shrubs and trees, as well as weed hosts.

Seasonal incidence- The spotted pod borer's seasonal occurrence differed based on the crop and season in various areas. *M. testulalis* reaches its highest activity in July, August and October (Lalasangi et al., 1988). In moth captures from light traps at Bundelkhand University, Agricultural Farm, Jhansi, two population peaks have been observed: the first peak in September and the second peak in early November to mid-December. That found the peak larval activity coincided with peak flowering stage in black gram.


Larvae with Internal damage Symptom


External Symptom


Adult

Damage Symptom/Stages of Spotted Pod Borer

Nature of damage- Adults prefer flower buds, seeds, terminal shoots, and tender pods to lay their eggs on. Young larvae (1st, 2nd, and 3rd instars) injure the terminal shoots and flower buds the most after hatching, while older larvae (4th and 5th larval instars) injure the open flowers and pods the most. The larvae eat from a webbed mass of leaves, flowers, vine buds and other plant parts. Older larvae are extremely agile, feeding constantly on flowers and freshly shaped pods and wreaking havoc all over the place. period of crop reproduction. Normally, larvae eating on the anthers, filaments, styles, stigma, and ovaries of flowers and move from flower to flower, consuming 4-6 flowers before reaching adulthood. Larvae in the third to fifth instars will bore into pods and, on rare occasions, peduncles, and stems. Pods are preferred by third instar larvae over flowers and leaves, while flowers are preferred by first instar larvae. Though female moths lay eggs during the growing season, the damage is concentrated during the flowering and podding periods, young larvae eat flowers, while mature larvae eat the fruits and pods of black gram.

Biology of spotted pod borer-

Egg: Flat, somewhat elongated, on tiny and fragile chorion, pale yellowish eggs with faint reticulates culpturing. The undersides of stems, terminal shoots, and flower buds are glued with eggs. Eggs are laid singly or in batches of 2-6 and are milky white, flattened dorsoventrally, and oval on the underside of stems, terminal shoots, and flower buds. When they are freshly laid, the eggs are milky white, oval, dorsoventrally flattened, and fixed to the substrate.

Larva: Mature larvae have a translucent body with two dark brown spots on each segment and are 17-20 mm long. The amount of spotting depends depending on the host, and some larvae were discovered without spots. In the larval stage, there were five instars. The head capsule is light to dark brown, and the prothoracic plate is dark brown and broken dorsally. Until pupation, the spots become indistinct. The larvae are photonegative and active in the evenings, feeding on the plant all night. There are five larval instars, each lasting 8-10 days order pending on the atmosphere and host species, it can take up to 16 days. Many that fed the larvae artificial food had a reduced lifespan. The insect's biology is alsoaffected by the larval feed portion, which preferentiallyfeeds on the host plant's reproductive organs for around three weeks before migrating to the pods to pupate.

Pupa: The pupal period lasted 8 to 10 days on Blackgram. The pupae are elongated and have as houlder-like shape, measuring about 13 mm in length. The early pupal stage is greenish, but when fully grown, it turns brown and is hidden in a cocoon made of dry leaves, flowers, and other dead plant matter. Normally, the pupal cycle lasts one to two weeks. During the dry season, there is no evidence of diapause.

Adults: Moths have medium size of fuscous brown forewings and a lunulate black-edged white dot at the cell's end. A black-edged, semi-hyaline band protruded beyond the cell from beneath the costa. With a fuscous mark at the base and a spot at the cell's upper angle, the hind wings were semi-hyaline white. From costa to vein1c, a marginal fulvous brown fuscous band with aninner irregular edge ran. Both sexes had identical morphology. The maximum proportion of mating and oviposition happens within the first four to five nights of pairing and the ideal temperature range for this is between 20 and 25°C with a humidity of 80 percent or higher.

Management practices-

Farmers use a variety of approaches to control *M. vitrata* and other insect pests, depending on their experience and financial situation. Despite the high cost and other drawbacks of chemical insecticides, extensive research has shown that they are the most used. **Biological control:** It is an alternative to chemical pesticides, have gained popularity in the fight against insect pests in recent years, and be a safer control approach to some degree. Natural enemies (parasitoid e.g., *Phanerotomaleucobasis*, *Pristomerus* sp., *Testudobracon* sp. *Apanteles taragamae*) of *M. vitrata* eggs. *M. vitrata* Multi Nucleopolyhedroviral and entomopathogenic fungi are examples of entomopathogenic viruses and fungi. Isolates of *M. anisopliae* and *B. bassiana, Bacillus thuringiensis.*

Botanical control: Botanicals have a lot of potential against *M. vitrata* It has only recently been discovered that vitrata exist. It has been recorded that a neem concentration of 50,000 ppm causes 90 percent larval mortality. Allium sativum bulb, *Piper guineense* and *Azadirachta indica* seed extracts were found to be effective in reducing egg hatch, with black pepper and garlic bulb having the highest reduction of all levels of concentration.

Cultural Control: Cowpea damage is reduced by cultural activities such as intercropping, weeding, planting time, and density. Planting at 30 x 20 cm 2or 60 x 20 cm 2at the start of the rain will help minimize.

Pheromones and Traps: In recent years, the use of sex pheromones and in the control of *M. vitrata* populations, traps have proven to be extremely useful and complementary. Many studies on the sex pheromone of insect pests of legumes using *M. vitrata*. 10,12-hexadecadienol and (E)-10-hexadecenal are minor components, while (E, E)-10,12-hexadecadienal is a major component.

Chemical insecticides: Several studies on spotted podborer insecticidal control in various crops and locations were available.

- ✓ Monocrotophos and endosulfan, both at a weight of 0.5 kg a.i.
- ✓ Two sprays of 0.05 percent dimethoate and 0.05 percent monocrotophos were safe.
- ✓ The use of sprays of 0.008 percent cypermethrin (1st at flower initiation, 2nd at 50% flowering, 3rd at100% flowering, and 4th at 100% pod set)
- ✓ Triazophos, endosulfan,and monocrotophos effectiveness
- ✓ The use of cypermethrin, deltamethrin,fenvalerate, and endosulfan (three sprays) against pod borers.
- ✓ Sprays of chlorpyriphos @ 0.05 percent at ten-day intervals were successful in decreasing the larval population of *M. vitrata* on the black gram.
- ✓ Treated with chlorpyriphos + DDVP at 2.5 + 1 ml/l. (Malathi et al., 2007) found that at 50 percent flowering stage, chlorpyriphos 20 EC @ 2.5 ml/l caused the largest reduction in *M. vitrata*
- ✓ Spinosad 45 EC @ 0.4 ml/lit and indoxacarb14.5 EC @ 0.4 ml/lit were the insecticides that did the least pod damage in black gram.

- ✓ Indoxacarb 14.5 SC and Spinosad 48 SC were highly selective against *M.vitrata* third instar larvae.

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Honey Bees, Wasps and Hornets Stings in Animals

[1]Dr. Azeer Alam, [1]Dr. Jitendra Pratap Singh, [1]Dr. Satyavrat Singh, [2]Dr. Abhishek Kumar Verma and [2]Dr. Kabir Alam

Department of Veterinary Medicine, Department of Veterinary Gynaecology & Obstetrics
C.V.Sc. & A.H., Acharya Narendra Deva University of Agriculture and Technology, Ayodhya, U. P.

Honeybees, Wasps and Hornets, the flying insects of order Hymenoptera, are distributed worldwide and are significantly hazardous to human beings and animals. The medically important groups of Hymenoptera are the Apoidea (bees) and Vespoidea (wasps, hornets, and yellow jackets). Attacks by these insects are particularly a problem in wooded hilly areas, groves and park etc., where swarms of bees are found hanging from the boughs of trees, in caves and on the walls of abandoned houses. These insects deliver their venom by stinging their victims. Bees lose their barbed stinger after stinging and die. Wasps, hornets, and yellow jackets can sting multiple times. Cattle, buffaloes, equines, dogs, etc., tethered under the shady trees harbouring honey bees hives may receive a fatal assault by these flies. Attack may be provoked by children hurling stones at the hives or when noisy equipments such as tractors, thrashers, lawn mowers etc., are operated in areas too close to honey bee hives. In addition, bees when en-route to new colonies may invade stables or yards where in horses, cattle, buffaloes or other animals are housed. The toxic components of venom of these insects contain histamine, serotonin, kinins, hyluronidase, phospholipases, A and B, peptides and formic acid. Bee venom also has mellitin, and formaldehyde. All animals are susceptible to the toxic effects of insect sting. The flying insects are capable of injecting up to 50 micro litre of venom with each sting. **Clinical Signs**

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Bee, Wasp, and Hornet stinging show both localized and systemic toxicity signs. Clinical sign can appears immediately following the sting up to 30 minutes later and might last for hours.

Localized Toxicity-

- Mild to severe pain, heat and swelling around the sting or biting area
- Sting area may be pinkish-red in colour
- Itching produces at swelled area
- Area adjacent to the site of sting may also involve in the large local reaction

Systemic Toxicity-

- In animals systemic toxicity due to multiple stinging may cause redness or swelling at site on body distance from the site of sting such as muzzle, eye lids, lips, tongue and vulva.
- Pain and swelling may result in pronounced excitement.
- In severe cases in horse there may be diarrhea, haemoglobonuria, trachycardia, jaundice sweating and prostration occurs.
- In case of reaction can be severe with closing of airway and perhaps shock.
- In rare cases the attack is fatal

Diagnosis-

- On the basis of history of animals
- On the basis of clinical sign (multiple stings of bees may be associated with severe local swelling upto 6 cm in diameter)
- In insect stings laboratory evaluation have little value, except that stress related leucocytosis may be present

Treatment and Management

Specific antidotes for venomous insects are not available

- First the stinger removed (if it remains) by scrapping across the site with a blunt edged object such as post-card.
- The stinged area should be washed well with soap and water and applying ice to reduce the swelling, oedema and pruritis.
- Application of locally weak solution of ammonia or sodium bicarbonate also helps
- The stinged area should be rubbed with anti-histamine cream
- Administration of an analgesic as well as glucocorticoid such as prednisolone may be helpful in large local reaction
- Adrenaline is the drug of choice for systemic sting reactions. In mild to moderate cases administered subcutaneously. In the case of severe hypotension, adrenaline may be used intravenously.
- Combined use of H_1 and H_2-histamine receptors antagonists has been decrease the severity of late phase cutaneous reactions.
- If adrenaline therapy alone is not adequate then intravenous fluids and aggressive cardiopulmonary resuscitation should be provided.

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Who Owns the Plant Genetic Resources?

Senthilkumar V.[1], Priya Garkoti[2] and Anu Singh [3]

[1] Junior Research Fellow, ICAR - VPKAS, Almora, Uttarakhand.
[2] Ph. D. Research Scholar, GBPUAT, Pantnagar, Uttarakhand.
[3] Young Professional -II, ICAR - VPKAS, Almora, Uttarakhand.

Introduction

Plant Genetic Resources (PGR) form the cornerstone of global food and agricultural security. These resources encompass traditional varieties, wild relatives, landraces, and modern cultivars critical for breeding resilient crops. The question of ownership over PGR is complex and involves multiple stakeholders, including governmental and non-governmental agencies. Government institutions like ICAR-NBPGR and international bodies such as FAO and CGIAR play a vital role in conservation, evaluation, and distribution of germplasm. Simultaneously, farmers and NGOs contribute significantly by preserving indigenous varieties and promoting biodiversity awareness. Understanding the diverse ownership and stewardship of PGR is essential for ensuring equitable access and sustainable utilization.

Types of owns the plant genetic resources

1. Governmental agencies
2. Non- Governmental agencies

1.Governmental agencies

The primary purpose of a national /international system is to ensure that the genetic resources needed in agriculture, forestry, and conservation programs are available, evaluated, conserved, and used.

This is a long-term requirement to safeguard national food production now and, in the future, and it should be a responsibility of an official public agency.

1. International programmes/agency
2. National programmes/agency

1.International programs/agency

Food and Agriculture Organization

- FAO convened the first international meeting on plant genetic resources in 1961
- FAO also established a crop ecology and genetic resources unit 1968 to deal with activities related to the collection, conservation, and documentation of genetic resources (Williams, 1984).
- Two major technical conferences, in 1967 and 1973, specially on genetic resources were co-sponsored by the International Biological Programs and FAO.
- FAO Conference,41st Session, Rome, 22-29 June 2019

Consultative Group on International Agricultural Research

- The internationalization of germplasm was provided with the establishment of the international agricultural research centres (IARCs) in the Consultative Group on International Agricultural Research (CGIAR)
- The CGIAR system was established in 1971, at which time there were four operational IARCs .
- These and subsequent CGIAR centres, large germplasm collections as a consequence of their work on particular crops.
- It represents a major element of an **emerging global germplasm conservation system.**

International Board for Plant Genetic Resources

- CGIAR approved the formation of the International Board for Plant Genetic Resources (IBPGR) In 1974, IBPGR was organized to be associated with FAO in Rome, Italy.
- FAO provided logistical support to IBPGR and continued publishing its documents related to germplasm activities including its genetic resources newsletter.

European Association for Research on Plant Breeding

- In 1959 the European Association for Research on Plant Breeding (EUCARPIA) established the Wild Species and Primitive Forms Section (currently, the Genetic Resources Section).
- Since 1960, genetic conservation and the danger of genetic erosion in wild species and primitive forms have become major concerns of the association.

2.National agencies/programmes ICAR-NBPGR

- The National Bureau of Plant Genetic Resources (ICAR-NBPGR) was established by the Indian Council of Agricultural Research (ICAR) in 1976 with its headquarters at New Delhi
- The operations are administered by Divisions of Plant Exploration and Germplasm Collection, Germplasm Evaluation, Germplasm Conservation, Genomic Resources and Plant Quarantine in addition to the Units of Germplasm Exchange and Tissue Culture and Cryopreservation.

ICAR-NBPGR has the network of 10 Regional Stations covering different ago-climatic zones to carry out PGR activities including collection, characterization, evaluation, and maintenance of various crops as mentioned below:

- ***Shimla (Himachal Pradesh):*** Established in 1960; temperate crops.
- ***Jodhpur (Rajasthan):*** Established in 1965; Agri-horticultural crops germplasm of arid and semi-arid zones.
- ***Thrissur (Kerala):*** Established in 1977; Agri-horticultural crops germplasm of southern peninsular region with particular emphasis on spices and plantation crops.
- ***Akola (Maharashtra):*** Established in 1977; Agri-horticultural crops germplasm of central India and Deccan Plateau.

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- ***Shillong (Meghalaya):*** Established in 1978; Agri-horticultural crops germplasm of north-eastern region including Sikkim and parts of north Bengal.
- ***Bhowali (Uttarakhand):*** Established in 1985; Agri-horticultural crops germplasm of sub-temperate region.
- ***Cuttack (Odisha):*** Established in 1985; Agri-horticultural crops germplasm of eastern peninsular region with main emphasis on rice germplasm.
- ***Hyderabad (Telangana):*** Established in 1985; Quarantine clearance of Agri-horticultural crops germplasm of Telangana, Andhra Pradesh, and adjoining areas.
- ***Ranchi (Jharkhand):*** Established in 1988; germplasm of tropical fruits and other field crops of Bihar, eastern Uttar Pradesh, Jharkhand, and West Bengal.
- ***Srinagar (Jammu & Kashmir):*** Established in 1988; Agri-horticultural germplasm of temperate crops

National Gene bank at NBPGR

Germplasm conservation at ICAR-NBPGR Seedbank, (as of April 2025)

Category	**Crop/Material**	**Accessions Stored**
Cereals	Paddy	118565
Cereals	Wheat	36285
Cereals	Maize	12041
Cereals	Others (Cereals)	10822
Millets & Forages	Sorghum	26397
Millets & Forages	Pearl Millet	8454
Millets & Forages	Minor Millets	25811
Millets & Forages	Oats	1420
Millets & Forages	Clover	625
Millets & Forages	Teff	300
Millets & Forages	Marvel grass	341
Pulses	Chickpea	14907
Pulses	Pigeonpea	11991
Pulses	Mung Bean	4484
Pulses	Pea	4726
Pulses	Cowpea	4056
Pulses	French Bean	4276
Pulses	Clusterbean	4353
Pulses	Horsegram	3182
Pulses	Ricebean	2246
Pulses	Others (Pulses)	15137
Oilseeds	Groundnut	13893
Oilseeds	Oilseed Brassica	12474
Oilseeds	Safflower	7500
Oilseeds	Sesame	10518
Oilseeds	Soybean	5529
Oilseeds	Sunflower	2014
Oilseeds	Others (Oilseeds)	11584
Oilseeds	Cotton	11696
Vegetables	Tomato	2942
Vegetables	Brinjal	4867
Vegetables	Chilli	5426
Vegetables	Okra	4275
Vegetables	Onion	1152
Vegetables	Others (Vegetables)	11228
Spices & Medicinals	Buchanania	97
Spices & Medicinals	Opium Poppy	533
Spices & Medicinals	Ocimum	850
Spices & Medicinals	Tobacco	2293
Spices & Medicinals	Others (MAPs)	5903
Others	Coriander	1217
Others	Fenugreek	1475
Others	Others (Spices)	1026

2. Non-Governmental agency

Farmers - "owns the landraces"

- They created diversity a wealth of plant genetic diversity of global importance for food and agriculture.

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- With their knowledge and skills, they managed and conserved the food crops that feed the world today.

NGO - "Public awareness"

- **Greenpeace** -International NGO with a goal to "ensure the ability of the Earth to nurture life in all its diversity."
- **Fauna and Flora International**- Works to conserve threatened species and ecosystems worldwide into account human needs.
- **Nature Friends International**- Global environmental umbrella organization.
- **International Union for Conservation of Nature** -Union composed of government and civil society organizations to provide the knowledge and tools that enable human progress, economic development, and nature conservation to take place together.
- **Nature Conservancy**- Conservation organization working to protect ecologically important lands and waters for nature and people.
- **Natural Resources Défense Council** - International environmental advocacy group with a staff of hundreds of lawyers, scientists, and policy experts.
- **World Agroforestry Centre** -Generates knowledge about the benefits of agroforestry to develop policy and practices for improved livelihoods and environmental benefits.
- **World Wildlife Fund** - International Conservation Organization - see also the International Secretariat based in Geneva.

Benefits for PGR conservations

- It helps in tapping crop genetic diversity and assembling the same at one place
- It reduces the loss of genetic diversity due to genetic erosion
- Material of special interest during exploration trips new plant species during the process of collection also help in serving certain genotypes from extinction.

Conclusion and Future Prospects

The conservation and ownership of Plant Genetic Resources (PGR) are shared responsibilities between governments, international organizations, local communities, and non-governmental agencies. While national agencies like ICAR-NBPGR safeguard genetic diversity through structured programs and gene banks, farmers continue to play a vital role in maintaining traditional landraces. International initiatives such as those by FAO and CGIAR further enhance global collaboration and access to genetic resources. However, issues of access, benefit-sharing, and intellectual property rights remain critical.

Looking ahead, stronger legal frameworks, inclusive policies, and technological advancements—such as genomic tools and digital documentation—will enhance conservation and equitable use. Promoting farmer participation, expanding community seed banks, and fostering international cooperation will be key to securing PGR for future food and environmental resilience.

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Revitalizing Indigenous Technical Knowledge (ITK) for Sustainable Plant Disease Management

[1]Pandimeena I, [1]Naresh. J and [2]Akshaya S. B

[1]PG Scholar, [2] Assistant Professor (Plant Pathology), Department of Plant Pathology, SRM College of Agricultural Sciences, SRMIST, Chengalpattu

Introduction

Reviving Indigenous technical knowledge (ITK) to treat plant diseases offers a fresh and long-term approach to today's agricultural issues. Centuries of observation, ecological wisdom, and interaction with the environment have led indigenous communities to develop distinctive and particular plant health management techniques. The potential of integrating ITK into current plant disease management techniques to improve biodiversity, lessen dependency on artificial chemicals, and foster agroecological resilience. The world is currently dealing with a rise in environmental sustainability, biodiversity loss, and climate change. Therefore, assessing environmentally friendly and sustainable agricultural practices becomes more challenging. The term "Indigenous technical knowledge" describes the collective wisdom and methods created by the Indigenous people of different nations, which provide useful methods for controlling and preventing plant diseases and pests while also improving agricultural adaptability. Modern agriculture should look beyond conventional approaches to identify innovative ways to revive indigenous technical expertise in plant disease management. Furthermore, the revival of ITK in plant disease control may offer a vital connection between historical and contemporary farming methods, paving the way for a more inclusive and sustainable future. Innovative, sustainable, and affordable methods of managing plant diseases by fusing traditional technical knowledge with contemporary methods.

Indigenous Technical Knowledge

ITK means the traditional knowledge, practices, and beliefs of indigenous and local communities, which have been developed over generations through direct experience and close interaction with their environment. This knowledge includes holistic and ecological approaches to agriculture, focussing on effective strategies for the prevention and management of plant diseases and pests. ITK encompasses various aspects, including pest and disease management, water conservation, and soil fertility enhancement. Indigenous farmers have been using their traditional knowledge (ITK) for plant disease control for thousands of years. It has helped them to maintain the quality of the soil and protect their crops without resorting to the use of pesticides. Nowadays, it is recognised that Indigenous Traditional Knowledge (ITK) contributes to climate change adaptation, biodiversity preservation, and environmental conservation.

Importance of Indigenous Technical Knowledge

Indigenous Technical Knowledge is crucial in plant disease management, offering various advantages that can improve agricultural practices. The fundamental values of ITK encompass

Sustainability: The primary focus of ITK relies on long-term ecological balance through sustainability. Indigenous Communities utilize techniques that could improve biodiversity, water conservation, and soil health to maintain pest and disease resistance. Moreover, ecologically friendly agricultural systems and ITK-based methods can reduce hazardous pesticides, fungicides, and fertilizers by emphasising sustainability.

Ecological Balance: ITK was intricately connected to the environment, animals, and plants. With this understanding, disease management strategies focus on maintaining an ecological balance that naturally prevents the disease from spreading. Companion planting, crop rotation, and the preservation of soil biodiversity are effective methods for naturally mitigating plant diseases and enhancing plant health.

Relevance to Culture: ITK is a culturally appropriate solution for farmers since it demonstrates the importance of Indigenous communities' cultural customs and values across various nations. Both adaptability and food security are improved by incorporating traditional methods and using Indigenous knowledge to ensure that agricultural practices are tailored to the community's unique needs.

Biodiversity conservation: The majority of Indigenous practices encourage the use of a broad range of plant species, which lowers crop susceptibility to disease outbreaks and promotes agricultural biodiversity. As a result, crops become more resilient to disease and environmental stress. This phenomenon is thought to be a key idea in contemporary plant disease management.

ITKs in Modern Agriculture

Indigenous Technical knowledge has greater potential since its application has been largely seen as the most favourable alternative for industrial agriculture and synthetic pesticides. The importance of ITK in advancing environmentally friendly and sustainable farming has come to light more and more in recent years. The integration of ITK into modern agriculture can provide benefits such as,

Natural Disease and Pest Management: ITK focuses on natural disease control strategies, like using local plants that have pesticide and antimicrobial qualities. Techniques such as intercropping have the potential to disrupt disease cycles. By serving as a substitute for chemicals, these methods lessen environmental contamination and safeguard biodiversity.

Reduced Dependency on Chemicals: Indigenous knowledge can assist us in reducing the need for chemical fertilizers and pesticides, which have negative environmental effects, in the context of natural disease prevention techniques. The shift to organic farming methods satisfies consumer demand for food and lifestyle choices that are free of chemicals and healthier.

Climate Change Adaptability: Indigenous farming methods are better able to withstand environmental stresses like floods, droughts, and temperature swings. These systems are ready to collaborate with regional settings to increase climate change adaptation.

Adaptation to Local Conditions: ITK is extremely adaptable because it was created and adapted over many generations in response to local environmental conditions. Indigenous farmers are better equipped to apply focused disease control strategies because they have a deeper understanding of microclimates, pest behaviors, and plant-pathogen interactions.

Cost-Effectiveness: Since the majority of indigenous practices use locally accessible resources, they are more reasonably priced for all kinds of farmers, including small-scale farmers. In the competitive market, synthetic fertilizers, pesticides, and genetically modified crops are more costly and less efficient, particularly for farmers in developing nations.

Indigenous Practices in Plant Disease Management

Indigenous communities have developed effective plant disease management strategies that are with very specific ideologies in ecological principles and sustainable practices. Some of these practices are,

- ✓ Many regions of Asia and Africa utilize neem (*Azadirachta indica*) products, such as leaves, oil, neem cake, and neem seed kernels. These products possess strong antimicrobial properties and are employed to manage fungal, bacterial, and viral diseases in both agricultural and Horticultural crops.
- ✓ Deep ploughing during the summer is effective in mitigating soil-burrowing nematodes and resting spores associated with soil-borne diseases.
- ✓ Farmers use ladybird beetles to control aphid populations in crop plants or utilize compost fortified with beneficial fungi (*Trichoderma* sp) and bacteria (*Bacillus* sp) to enhance soil health, promote plant growth, and prevent the growth of harmful pathogens.
- ✓ Cultural practices such as Timing planting, i.e., planting at specific times of the year, are critical for disease prevention. Timing plantings to avoid high-risk periods for certain diseases, such as fungal infections during the rainy season, can effectively reduce the incidence of crop diseases. Eg, Early planting of cumbu (June- July) will reduce cumbu ergot (*Claviceps purpurea*).
- ✓ Application 10% mahua cake extract (*Madhuka indica*) will reduce the growth of *Sclerotium rolfsii* and significantly reduce the root knot nematode infestation.
- ✓ Mahua cake extract combined with dishwashing powder is used to control bacterial blight disease.
- ✓ To control the banana bunchy top virus, tribal people utilize ash dusting and tanned leather waste liquid.
- ✓ To prevent seed-borne disease and enhance seed germination in ginger and turmeric, farmers use cow dung slurry as a seed treatment.
- ✓ Fresh cow dung is sprayed on chillies in the collar area to control damping off and die-back.
- ✓ Crop rotation with marigolds will reduce bacterial wilt of solanaceous and root-knot nematode infestation.
- ✓ To prevent bacterial and viral diseases in vegetable crops, spray a fermented mixture of 5 kg of cow dung, 5 litres of cow urine, and 15 grams of lime in 100 litres of water.

- ✓ Spraying of raw milk will effectively control the downy mildew disease in pearl millet.
- ✓ The spraying of a cow urine and buttermilk mixture will effectively control rust disease.
- ✓ Applying leaf and root extracts of marigolds will control root rot and nematodes.
- ✓ Growing trap crops such as marigolds in bhendi, cucurbits, and cowpea fields will reduce the vector population
- ✓ Applying 2kg of papaya leaf extract in 3-4 litres of water, combined with 250 ml of soap solution as a surfactant, will effectively reduce the brown spot on rice.
- ✓ Applying an ash mixture during the panicle initiation stage in paddy can effectively mitigate the occurrence of brown spot in rice.
- ✓ Mix the seeds with dried leaves of notchi, neem, and pungam to reduce storage pests and diseases
- ✓ Spraying of buttermilk along with *Bacillus* sp will reduce the chilli leaf curl disease.
- ✓ Spraying of 5 % neem seed kernel extract will control sheath blight and rice tungro virus in rice
- ✓ Spraying of 10% *Prosophis julifera* leaf and fruit extract will reduce the rice blast disease
- ✓ Spraying of 10 % *Calotropis* leaf extract will reduce the root rot disease in pulses.
- ✓ Applying leaf extracts of adathoda, notchi, and datura on pulses and paddy crops can effectively diminish the incidence of *Rhizoctonia solani* and bacterial blight diseases.

Conclusion

Revitalizing plant disease management through indigenous technical knowledge offers a promising way toward more sustainable, resilient, and eco-friendly farming systems. By integrating the ideas and knowledge of indigenous communities, Today's modern agriculture can move away from dependency on harmful chemicals and hold the cultural organic practices that promote biodiversity, reduce costs, and enhance food security. This requires a strong effort to preserve, share, and value indigenous knowledge, ultimately leading to a more holistic approach to plant disease management that benefits both farmers and the environment.

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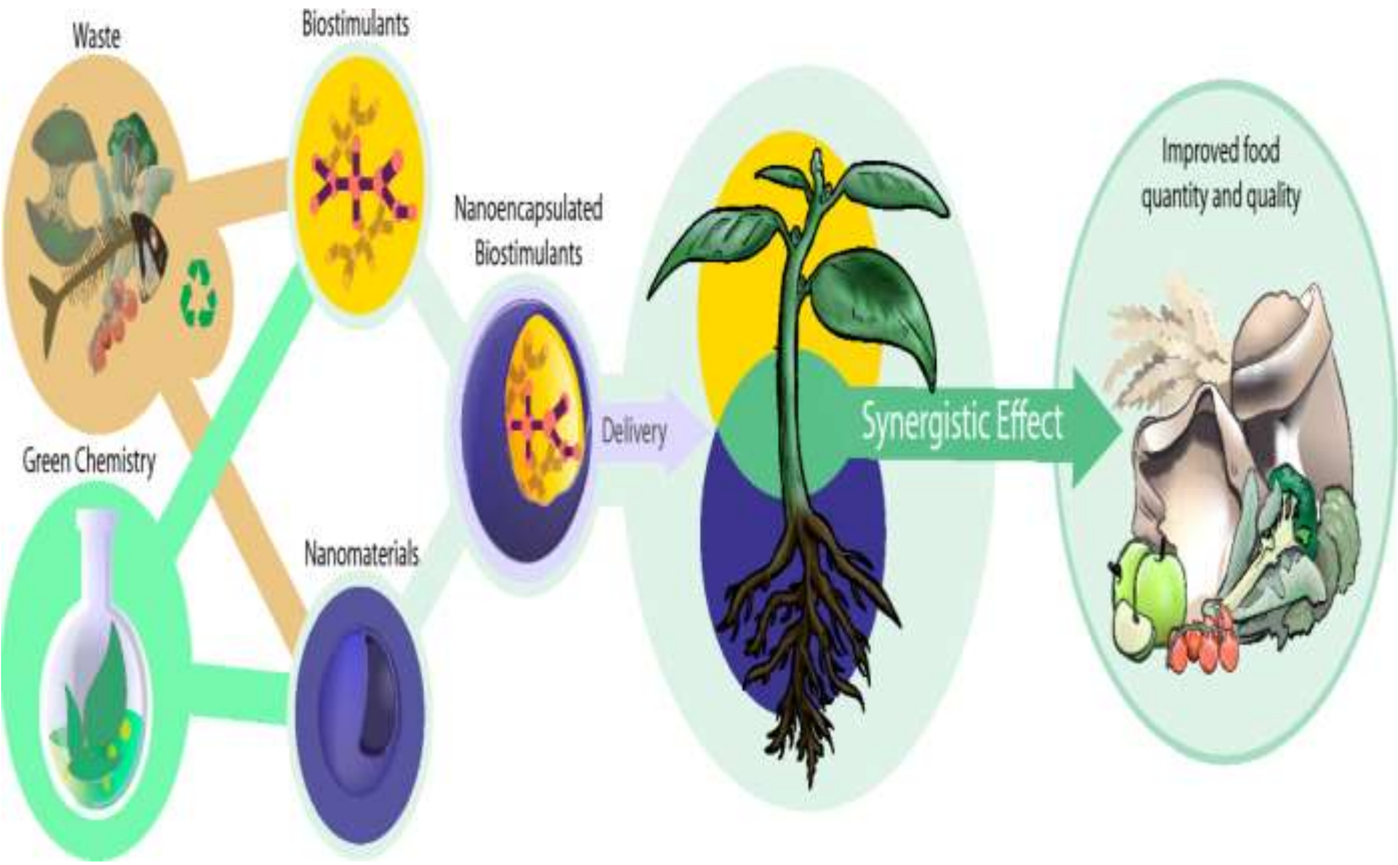

Nanotechnology in Horticulture: Innovations for a Greener Future

Anjali Kumari Jha[1], Kumari Punam Sinha[1], Mamoni Deori[1], Lipika Nath[1], Alok Kumar[1], Prince Kumar[2]

[1]Ph.D. Research Scholar, Uttar Banga Krishi Vishwavidyalaya, Pundibari, Cooch Behar

[2]M.Sc. Research Scholar, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar

Nanotechnology, an advanced and rapidly evolving field, has emerged as a game-changer in horticulture by significantly enhancing crop production, plant health, and resource efficiency. Various nanostructures, including nanoparticles, nano sensors, and nano emulsions, are being utilized to boost nutrient absorption, stimulate plant growth, and alleviate abiotic stresses such as drought and salinity. Thanks to their distinctive properties, nanoparticles provide innovative approaches for crop enhancement and protection. The application of nanomaterials like nano fertilizers improves nutrient use efficiency, minimizes environmental impact, and maximizes resource utilization. Likewise, nano pesticides offer superior effectiveness in managing pests and diseases, thereby reducing dependence on traditional chemical solutions. Moreover, nanotechnology plays a crucial role in regulating plant growth processes. Its contributions to horticulture are vast and continually evolving, ranging from optimizing nutrient management to transforming pest control and growth regulation. With its immense potential, nanotechnology is paving the way for more sustainable and efficient horticultural practices.

Introduction

Nanotechnology has become a promising tool in horticulture, providing innovative solutions to various challenges related to crop production, pest control, and post-harvest preservation. Key nanostructures such as nanoparticles, nano sensors, and nano emulsions are being employed to enhance

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nutrient absorption, promote plant growth, and alleviate abiotic stresses like drought and salinity. Nanoscale delivery systems enable the precise and controlled release of growth regulators, allowing for better modulation of plant development and flowering. This targeted approach improves both crop yield and quality while reducing environmental impact.

Nanotechnology also enables controlled delivery of agrochemicals, optimizing their use and minimizing environmental contamination. The nano-sizing of fertilizers improves nutrient availability at the cellular level, leading to greater nutrient uptake efficiency. Nanoparticles play a role in accelerating seed germination, increasing agricultural output, and enhancing chlorophyll content, thereby boosting plant growth through improved absorption. Nano fertilizers containing essential micronutrients such as zinc (Zn), copper (Cu), and iron (Fe) help overcome soil fixation issues and enhance photosynthetic efficiency.

Furthermore, nano-based coatings and packaging materials help extend the shelf life of horticultural produce, reducing post-harvest losses and ensuring food safety. Nanosensors provide real-time monitoring of environmental factors, offering critical data for precision agriculture. These nanomaterial-based sensors can detect fluctuations in soil moisture, nutrient availability, and plant health, enabling timely corrective actions for optimal crop management.

In addition to improving productivity and resource efficiency, nanotechnology contributes to environmental sustainability by addressing issues associated with traditional farming practices. For instance, nanoscale zero-valent iron (nZVI) has demonstrated potential in remediating contaminated soils by breaking down or immobilizing harmful pollutants. By enhancing soil health and fertility, nanotechnology supports ecosystem sustainability and biodiversity conservation in agricultural landscapes.

Different types of nanomaterials

Nano Fertilizers:

Nanostructured fertilizers represent a significant advancement in nutrient management within horticulture. These formulations enhance the efficiency of nutrient absorption by plants, reducing fertilizer requirements and minimizing nutrient leaching into water sources. Controlled-release nano fertilizers supply nutrients gradually over an extended period, ensuring consistent availability for sustained plant growth and productivity.

Nano Pesticides:

The application of nanotechnology has led to the development of nano-formulated pesticides that offer superior effectiveness with a lower environmental footprint compared to traditional pesticides. Nanoparticles facilitate precise delivery of pesticides to target pests, reducing unintended environmental dispersion. Additionally, nano-encapsulation of pesticides enhances their longevity and effectiveness while minimizing the likelihood of resistance development in pests.

Nano Sensors:

Nanotechnology-based sensors play a vital role in precision horticulture by providing real-time monitoring of soil health, nutrient content, and plant conditions. These sensors generate accurate data that help farmers make well-informed decisions regarding irrigation, fertilization, and pest control strategies. By optimizing resource use and reducing waste, nano sensors contribute to sustainable agricultural practices and improved crop yields.

Nanomaterials for Soil Remediation:

Soil contamination presents significant challenges to horticultural productivity and environmental well-being. Nanotechnology provides innovative solutions for soil remediation through the use of nanoparticles such as nanoscale zero-valent iron (nZVI). These nanoparticles effectively degrade or immobilize pollutants, helping to restore soil fertility and mitigate environmental degradation.

Nanomaterial-based soil remediation is a cost-effective and eco-friendly approach to addressing pollution challenges.

Nanoencapsulation of Plant Growth Regulators:

Nanoencapsulation technology allows for the precise and efficient delivery of plant growth regulators (PGRs) to specific plant tissues, enhancing their effectiveness and reducing environmental risks. Encapsulated PGRs are safeguarded from degradation and exhibit controlled-release properties, ensuring prolonged physiological benefits. This technology plays a key role in boosting crop productivity, improving stress tolerance, and enhancing post-harvest quality, thereby supporting sustainable horticultural practices.

Chemicals Used in Nano Technology

Chemicals used in nano technology are Calcium hydroxide ($Ca(OH)_2$), Orthophosphoric acid (H_3PO_4), sodium hydroxide (NaOH), Trisodium citrate ($Na_3C_6H_5O_7$), Urea molecules ($(CO(NH_2)^2)$), Other chemicals including zinc chloride ($ZnCl_2$), copper chloride ($CuCl_2$), and ferrous chloride ($FeCl_2$)

Use of Nanofertilizers in Horticulture

Nano-Fertilizers in Horticulture

Nano-fertilizers are becoming increasingly important in horticulture due to their potential to meet the specific nutrient needs and challenges of growing fruits, vegetables, and ornamental plants. Effective nutrient management is crucial for maximizing crop quality and yield, and nano-fertilizers offer a promising solution by delivering nutrients to plants in a controlled and targeted manner. This precision ensures that crops receive the right nutrients at the right time and in the appropriate amounts, leading to healthier plants with greater resistance to diseases and pests. Their nanoscale properties enhance the penetration of plant tissues, improving nutrient absorption and utilization. This not only reduces fertilizer waste but also supports sustainable agriculture by minimizing nutrient runoff and groundwater contamination. By increasing nutrient use efficiency, nano-fertilizers help alleviate the negative effects of excessive fertilizer use, such as soil degradation and water pollution.

Application of Nano-Pesticides in Horticulture

Nano-pesticides have revolutionized horticultural pest management by offering precise, efficient, and eco-friendly solutions. Their nanoscale size ensures better adhesion, thorough coverage, and penetration of pest barriers, enhancing control while reducing pesticide use and environmental impact. Slow-release formulations provide prolonged protection, improving crop yield and quality while lowering application frequency and costs. Additionally, their targeted action minimizes residues on produce, ensuring food safety and regulatory compliance.

Nano Sensors in Horticulture

Nano sensors are driving significant progress in horticulture by revolutionizing crop monitoring and management. These tiny sensors, composed of advanced nanomaterials, are used in agricultural environments to gather real-time data on crucial factors affecting crop health and productivity. In horticulture, nano sensors are instrumental in assessing soil conditions with remarkable accuracy, measuring parameters such as moisture levels, nutrient content, and pH. They also play a vital role in pest and disease management by detecting early signs of pathogen infections or pest infestations through changes in plant physiology or the presence of specific biomarkers. This early warning system allows growers to take timely action, reducing crop losses and decreasing dependence on chemical treatments. Additionally, nano sensors contribute significantly to precision horticulture by monitoring microclimatic variables such as temperature, humidity, and light intensity. By providing detailed data at a microscopic level, they enable the creation of optimal growth conditions in greenhouses and controlled environments, facilitating the year-round cultivation of high-value crops.

Nanomaterials in Seed Coating for Horticulture

The integration of nanomaterials in seed coating is gaining attention in horticulture due to their potential to enhance plant growth, boost yields, and improve

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resource efficiency. In the highly specialized field of horticulture, nano-engineered seed coatings offer several benefits. These coatings form a protective shield around seeds, ensuring successful germination and early-stage development. One of the primary advantages of nanomaterial-based seed coatings is their ability to safeguard seeds from environmental threats such as pests, diseases, and unfavorable weather conditions. Acting as a protective barrier, nanoscale materials shield seeds during the critical germination and early growth phases, leading to improved germination rates and the development of healthier, more resilient plants. Additionally, nanomaterial seed coatings can encapsulate vital nutrients, growth stimulants, and beneficial microorganisms, enabling their controlled and targeted release to young seedlings. This ensures that plants receive the necessary inputs for vigorous growth and development. By promoting efficient nutrient uptake and fostering beneficial microbial interactions, these coatings enhance overall plant vigor and productivity. Furthermore, nanomaterial coatings improve seed-to-soil adhesion, minimizing seed loss during planting and enhancing sowing precision, an essential aspect in horticulture where accurate seed spacing and placement are crucial for achieving optimal crop performance.

Nanotechnology for Soil Improvement in Horticulture

Nanotechnology enhances soil quality in horticulture by improving fertility, structure, and moisture regulation. Nanoparticles act as carriers for essential nutrients like nitrogen, phosphorus, and micronutrients, ensuring controlled release, better absorption, and reduced environmental risks. They also improve soil aggregation, water retention, and aeration, promoting strong root growth, drought resistance, and overall plant health. Additionally, nanotechnology aids soil remediation by binding pollutants and heavy metals, restoring fertility, and ensuring safe crop cultivation.

Nanobiotechnology for Disease Management

Nanotechnology-based solutions provide promising alternatives for plant disease control, reducing dependence on traditional chemical pesticides. Nano vaccines and nano-based carriers for antimicrobial agents enable precise delivery to plant pathogens, improving treatment efficiency while minimizing unintended side effects. Furthermore, nanomaterials such as silver nanoparticles possess strong antimicrobial properties and can be incorporated into disease management strategies to enhance crop protection while ensuring environmental safety.

Nanomaterials for Plant Protection

The use of nanoparticles with antimicrobial properties presents new possibilities for safeguarding plants in horticulture. Silver nanoparticles, for instance, have shown effectiveness against a wide range of plant pathogens, including bacteria, fungi, and viruses. By integrating nanomaterials into plant protection products, horticulturists can achieve effective disease control while reducing reliance on conventional chemical pesticides, thus minimizing environmental pollution and promoting sustainable farming practices.

Nanotechnology in Precision Agriculture

The incorporation of nanotechnology into precision agriculture enhances the ability to monitor and manage horticultural production systems with greater accuracy. Nanoscale sensors, drones, and remote sensing technologies provide real-time insights into crop health, soil moisture levels, and environmental conditions, empowering farmers to make data-driven decisions. By leveraging precision agriculture techniques enhanced with nanotechnology, horticulturists can achieve higher productivity, improved resource efficiency, and enhanced environmental sustainability.

Nanomaterials for Controlled Water Release

Water scarcity poses a major challenge to horticultural production, especially in arid and semi-arid regions. Nanotechnology provides innovative water management solutions by developing smart materials that can absorb and release water in response to environmental conditions. These advanced nanomaterials enhance water use efficiency by delivering moisture directly to plant roots while minimizing evaporation losses. As a result, they help improve crop productivity while promoting sustainable water conservation practices.

Nanomaterials for Post-Harvest Preservation

Post-harvest losses due to spoilage and decay remain a critical issue in horticulture. Nanotechnology offers cutting-edge solutions for extending the shelf life of fresh produce through the use of nano-based coatings and packaging materials. These advanced materials prevent microbial growth, reduce moisture loss, and protect produce from physical damage during storage and transportation. By improving preservation techniques, nanotechnology helps to reduce food waste and ensure the availability of high-quality produce for consumers.

Application of Nanotechnology in Vegetable Crops

Nanotechnology is transforming horticulture and the food industry by offering innovative applications in vegetable production. Commonly used nanomaterials in vegetable cultivation include silver nanoparticles, zinc oxide nanoparticles, and titanium dioxide nanoparticles. The advantages of nanotechnology in vegetable farming are substantial, ranging from effective pest management through nano-pesticides and nano-insecticides to enhanced productivity with nano-encapsulated fertilizers and bio-fertilizers. These advancements contribute to increased yields, improved crop quality, and sustainable agricultural practices.

Advantages of Nanotechnology in Horticulture

- **Precision Nutrient Delivery:** Nanoscale carriers enable the accurate and efficient delivery of nutrients to plants, ensuring optimal uptake, reducing fertilizer application, and minimizing nutrient runoff that can harm the environment.
- **Targeted Pest Management:** Nano-pesticides provide enhanced pest control by penetrating insect exoskeletons and plant tissues more effectively, reducing the frequency of pesticide use and lowering environmental contamination.
- **Improved Soil Quality and Water Retention:** Nanomaterials contribute to better soil aeration, reduced erosion, and enhanced drought tolerance, ultimately supporting healthier plant growth.
- **Extended Shelf Life of Produce:** By regulating gas exchange, moisture levels, and temperature in packaging materials, nanotechnology helps prolong the freshness of harvested fruits and vegetables, decreasing food waste and preserving quality.
- **Sustainability in Horticulture:** The adoption of nanotechnology promotes eco-friendly practices by reducing chemical inputs, maximizing resource efficiency, and minimizing environmental footprints.
- **Precision Crop Monitoring:** Nano sensors provide real-time insights into soil and environmental conditions, enabling farmers to make informed decisions that enhance resource efficiency and improve crop management strategies.
- **Controlled Release of Bioagents:** Nanotechnology supports the gradual release of beneficial microorganisms or biopesticides, fostering natural pest control methods and reducing reliance on synthetic chemicals.
- **Enhanced Crop Yield and Quality:** The integration of nanotechnology into horticultural systems leads to healthier plants, increased yields, and improved overall crop quality.

Challenges of Nanotechnology in Horticulture

- **Plant Uptake and Biotransformation:** The absorption, transformation, and movement of nanoparticles within plants can have both positive and negative implications, necessitating further research.

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- **Regulatory and Monitoring Gaps:** The absence of standardized formulations, thorough monitoring systems, and risk assessment frameworks hinders the effective development and deployment of nanofertilizers.
- **Impact on Soil Microbiology:** Nanomaterials can interact with soil microbes, potentially altering nutrient dynamics and influencing plant-microbe interactions.
- **Human Health Concerns:** Due to their ability to penetrate biological systems, nanoparticles used in spraying may enter vital organs such as the liver, brain, or heart, raising health concerns.
- **Environmental Risks:** If not properly managed, nanoparticles can accumulate in soil and water ecosystems, posing potential threats to non-target organisms and overall ecosystem health.
- **High Production Costs:** The expense associated with nanomaterial development and production can be a barrier to widespread adoption, particularly for small-scale farmers and resource-limited operations.
- **Public Perception:** Gaining public acceptance remains a challenge, highlighting the need for transparent communication about the advantages and potential risks of nanotechnology to build trust.

Conclusion

Nanotechnology has the potential to transform horticulture and contribute to environmentally sustainable agricultural practices. By utilizing nanomaterials, nano-devices, and nanoscale processes, key challenges in pest management, nutrient optimization, soil enhancement, water conservation, and post-harvest preservation can be effectively addressed. However, the widespread application of nanotechnology requires careful consideration of safety, regulatory compliance, and ethical concerns to ensure responsible and sustainable use. Collaboration among researchers, policymakers, industry stakeholders, and farmers is crucial to fully unlocking the benefits of nanotechnology for the progress of horticulture and global food security.

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An Eco-friendly, Intensive, Vertical Growing System of Strawberry Crop Production

[1]B. M. Yadgirwar* and [2]Dr.M.S. Babar
[1]Subject Matter Specialist (Horticulture), [2]Programme Coordinator
KVK, Borgaon Tal and Distt. Satara, Maharashtra

A full strawberry tower is an innovative way to grow lots of strawberry plants on a small size plot in field. Yields with the vertical hydroponic system do not yet match the yield per plant that the farm reaped with traditional soil grown strawberries, the higher plant density permitted by the vertical growing system has enabled small farmer to more than make up for this shortfall by allowing them to grow more plants in a smaller amount of space. Using Vertigo, innovative farmer Shri. Bhilare is able to situate nearly 96000 plants on one acre, whereas traditional system only allows for 18,000-20,000 plants per acre of land. The system also enables to reduce the labor costs as less preparation is required prior to start of the growing season. Sustainability is a major motivation, with this new system have drastically reduced water use and application of pesticides for management of soil borne pathogens.

Introduction

Strawberry is a delicious fruit consumed fresh and it also makes excellent ice cream and Jam on account of its rich aroma, and is also a good source of vitamin C. Mahabaleshwar contributes to 85% of the total Strawberry production in India. In India it is generally cultivated in the hills In Mahabaleshwar strawberry season begins around November 15 and lasts till the middle of April. Farmer Mr Kisan Bhilare, himself a farmer and Vice-President, All-India Strawberry Growers' Association and Chairman of Mahabaleshwar Phale, Phuleani Bhaji palasangh had introduced the concept of vertical farming of strawberry in village Bhilar, Tal.

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Mahabalshwar, Distt. Satara. This village is located between Hill station Panchgani and Mahabaleshwar.

Advantages

The most obvious is the ability to grow many plants on a small plot of land. While yields with the Vertigro vertical hydroponic system do not yet match the per plant yield that the farm reaped with traditional soil grown strawberries, the higher plant density permitted by the vertical growing system has enabled the farmer to make up for this shortfall by allowing them to grow more plants in a smaller amount of space. Using Vertigro, Shri. Bhilareis able to situate nearly 96,000 plants on one acre, whereas if surface grown only allows for 18,000-20,000 plants per acre of land.

- Sustainability is a major motivation, with this new system have no runoff and have drastically reduced water use.
- According to farmer the system also enables to reduce its labor costs as less ground land preparation is required prior to the start of the growing season.
- Since the plants are off the ground, fruits are grown very clean, very high-quality berries.
- Strawberries are susceptible to soil pathogens such as nematodes and leaf diseases such as anthracnose. In this innovative system Strawberries are less likely to get root diseases because there is no soil. Everything is grown in various percentages of cocopit.
- The strawberry produced in the vertigo system is much more uniform and produces up to 10 times more long stem strawberries than in the field. The berries hang over the pot and there is nothing to interfere with uniform growth. Premium berries brings a premium price.
- Planting and harvesting are much more efficient in the vertical system and there is very little need of replanting. In field strawberries, 15% of the plants may have to be replanted due to losses caused by a number of factors. Harvesting in the vertical system is done the same way as in t field except that there is no need of stooping. Harvesting strawberries in this vertical system is not that much tiresome and laborious as compared to traditional method. The system is thus low cost, durable, reusable, resalable, stackable, keeps the root temperature ideal, drains well, and is easy to replant.

Planting Material and Method:

The farmer has imported all strawberry rootstocks from California in the month of June to get the fruit in November. Varieties planted by him were Sweet Charlie, Camaraosa and Eliana.

Design of the Strawberry Towers

Here are the measurements used for strawberry towers:

- There are 50 towers erected in one row and such 12 rows of tower in 05 R area
- On each tower at bottom side (02 ft from ground) support of GI plate for laying thermocol potis fitted.
- On each tower 05 pots are mounted having bottom hole for draining water and water soluble fertilizer. The Tower to tower distance is 1m x 1m
- On the top of tower for every row one lateral is mounted for irrigation and fertigation
- At one side of corner fertilizer tank is placed at the corner of field.
- The vertical growing system allows for maximum plant density by fully utilizing the area

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- A total of 3000 pots with four plants in each, were evenly distributed. The final planting density was 05 times more than in field-
- Fertigation through drip emitters allowed conservative precise use of water and nutrient application.

Irrigation:

The farmers experienced with irrigation systems, with simplest arrangement for irrigation i.e. a dripper of 08 lph positioned at the top of the tower, and the water percolate down.

Growing Medium:

He used cocopeat in combination with perlite as the growing medium in pots. Plants grown hydroponically, meaning that all the nutrients required are delivered through fertigation only.

Perlite also provides excellent drainage of excess

water, while retaining a continuous film of water around each grain avoid to help prevent roots from drying out.

Fertilization:

Fertilization is done with soluble, balanced hydroponic nutrients. The ideal schedule is prepared so as to get strawberries during the third week of November. For fertigation'A' and 'B' tanks are fitted at the opposite corner of field. Through Tank A and Tank B, water soluble fertilizers are delivered through drippers located on the top of the first pot erected on the single tower. From planting to establishment plants are regularly fertilized daily. However, after 15 days of planting date fertigation is given on alternative days while during fruiting stage it is given at an interval of 04 days.

Planting method

Once towers are set-up and stabilized and the irrigation system is placed the pots are ready to plant. Then four plants are placed in pot at the corner, with care to plant the crowns at the proper depth. This vertigo system consists of a stack of high density polyethylene containers that nest for shipping. They are turned 90 degrees to stack and become a unique vertical growing system. This growing system holds four plants per pot this stack takes up less than 1.5 square feet of land space. Spaced out for the crops intended and the light availability, the system is capable of producing 6 to 8 times as much per square foot as the equivalent field crop. The plant density is 12000 plants in area of 05 R area in stacks of 5 pots, and 4 plants per pot. The Cost incurred on plastic mulching is also nil which is unavoidable in traditional system.

Plant Protection Measures

Farmer taking every care to keep ecosystem balance. Pests are controlled by spraying of botanicals like neem cake, extract of various leaves (Dashparni ark), so that natural predators are kept intact, pollinizers visit in large numbers.

Technology Details

Sr.No	Particulars	Details
01	Number of Tower Lines	12
02	Number of towers in each line	50
03	Number of pots on each tower	05
04	Number of seedlings in each pot	04
05	Area	05 R (500 Sqmt)
06	Total pots in 05Rarea	3000
07	Seedlings accommodated in 05R area	12000
08	Quantity of Coocpeat added per pot	1.5 Kg
09	Lateral diameter	16mm

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10	No of Lateral requirement	01 lateral/tower
11	Total laterals	12
12	Dripper discharge	08 lph
13	Number of Drippers per row	50 drippers/Row
14	Total drippers required for 05 R area	600
15	Varieties	Camarosa, Sweet Charlie, Eliana
16	Cost of per unit seedling	06 Rs
17	Total Seedlings	12000
18	Total cost of seedlings	Rs.72000
19	Yield/plant/picking	01 fruit (18 gm)
20	Number of pickings	75
21	Total yield from single plant	900 gm
22	Yield from 05 R area (12000 x 900 gm)	108Qtl
23	Labour requirement *	Nil
24	Average rate	55Rs/kg
25	Gross income from 05 R area	Rs594000

Note: Family labours are employed

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Is Natural Farming a Sustainable Alternative to Chemical Agriculture?

Sravani Arem[1], K. Archana[2]
[1]Ph.D Scholar, Dept. of Agronomy, Professor Jayashankar Telangana Agricultural University, Rajendranagar.
[2]MSc Scholar, Agronomy (Water management), Professor Jayashankar Telangana Agricultural University, Rajendranagar

Introduction

Modern chemical-based agriculture has increased the cost of production or reduced the crop yield due to various reasons. Growing of commercial mono crop year after year such as rice, wheat, cotton, and sugarcane results in the depletion of soil fertility, top soil infertile, soil vitality, ground water and mostly on the soil microbial population. Continuous use of chemical fertilizer, pesticide application, and crop residue burning can cause environmental pollution worldwide. Their continuous usage of chemicals decreases the soil micro and macrofauna which may directly affect on C-N ratio and nitrification activity. Natural farming is a method of chemical-free agriculture drawing from traditional Indian practices. In other sense, natural farming shows the importance of the synergistic effect on both plant and animal products on crop establishment, to build soil fertility and microorganisms (Smith *et al*.,2020). First time in Japan, Masanobu Fukuoka started work on natural farming, and his results showed that yields from natural farming are similar to the chemical farming without soil erosion and also maintains soil fertility for a longer time (Devarinti,2016). His results are compiled in a book "One Straw Revolution". Green revolution - brought a great change in Indian agriculture, which is rightly termed as transformation from "begging bowl to bread basket" and this was achieved with high yielding varieties and increased fertilizer use. Continuous use of only chemical fertilizer, crop residue burning and pesticide application can cause environmental pollution worldwide. Organic farming - the use of compost, vermicompost and neem cake and traditional additives have been practiced in India. Soil fertility status is maintained through organic manures, crop residues, green manure crops and use of bio-fertilizers such as Rhizobium, Azospirillum and Phosphobacteria which provide nitrogen and phosphorous nutrients to crop plants through nitrogen fixation and phosphorous solubilisation processes. In natural farming - The method involves locally available natural bio-degradable materials combined with scientific knowledge of ecology and modern technology with traditional farming practices based on naturally occurring biological processes.

History of natural farming

Masanobu Fukuoka was a Japanese farmer started work on natural farming, his results showed that yields from natural farming are similar to chemical farming but without soil erosion also maintains soil fertility for a longer time. He was a proponent of no-till, no-herbicide grain cultivation farming methods traditional to many indigenous cultures, from which he created a particular method of farming, commonly referred to as "Natural Farming" or "Do-nothing Farming". The system is based on the recognition of the complexity of living organisms that shape an ecosystem and deliberately exploiting it. He saw farming not just as a means of producing food but as an aesthetic and spiritual approach to life, the ultimate goal of which was "the cultivation and perfection of human beings".

Natural Farming (NF) was developed by Dr. Cho Han Kyu at the Janong Natural Farming Institute in South Korea. It was originally intended to change the chemical based and harmful farming methods that were being practiced in South Korea. Together with like-minded farmers, he converted his lifelong studies and his own experiences into an innovative farming system that not only promotes respect and care for the environment, but also produces more with less cost and labour.

Subhash Palekar method

➢ Zero Budget Natural Farming (ZBNF) is a method of agriculture that counters the commercial expenditure and market dependency of farmers for the inputs like seeds, fertilizers and pesticides.

➢ The principal methods of ZBNF include intercropping, green manures and compost, biological pest control, and mechanical cultivation. These measures use the natural environment to enhance agricultural productivity.

➢ Legumes are planted to fix nitrogen into the soil.

➢ Natural insect predators are encouraged.

➢ Crops are rotated to confuse pests and renew soil.

➢ Natural materials such as potassium bicarbonate and mulches are used to control disease and weeds.

Principles of natural farming

No ploughing: Natural farming does not till the land. Instead of using machines, we use earthworms, microorganisms and small animals. Machine can plough 20 centimeters at best, whereas earthworms will dig 7 meters. The excretions of the earthworm turn into the best soil. After practicing natural farming, the soil become soft. Because we don't till the land, the grass seeds in the soil do not come up to the surface. In other words, after the grass on the surface have germinated and died, you will have no more weeds problems. No tillage and no herbicide are linked.

No chemical fertilizers: Air, water and soil has all nutrients that plants require, and, in abundant quantities. Hence there is no need to add synthetic fertilizers from outside. The nutrients in the soil are in a "locked" form such that plants cannot use them. Plant exudates are the food for the microbes and they multiply, their predators multiply, and the entire soil food web gets activated. This triggers the exchange process between plants, soil microbes and nutrients. The plentiful locked minerals are made available to plants.

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No herbicides: Natural farming uses the weeds rather than killing them. We actually grow the wild grass such as rye and clover grass. The grass prevents soil erosion, holds moisture, propagates microorganisms, produces organic fertilizer, improves soil ventilation and supress the pests.

No pesticides: Natural farming does not use pesticide. Pesticides do not only kill insects; they reside in the soil and fruit. When absorbed, it can do serious harm to our bodies and even our next generations. Instead of using toxic chemicals, we use decortions to control pest.

Alternatives through natural farming-

- Seed treatment – Beejamrutha
- Herbicides – Mulching
- Fertilizers – *Jeevamrutha* and *Ghanajeevamrutha*
- Pesticides- Neemastra, Agniastra and Brahmastra
- Fungicides – Sour buttermilk and *Ginger kashaya*

Pilllars of natural farming

1. Beejamrutha: It is used as seed treatment, contains naturally occurring beneficial microorganisms. It is used for Seed treatment, applied as a coating either to seeds before sowing, or as a root dip before transplanting. Research studies showed that inoculating with *Beejamrutha* to protect the crop from harmful soil borne pathogens and young seedlings roots from fungus and soil borne and seed borne diseases and also help to produce IAA and GA3.

2. Jeevamrutha: It is a solid amendment, inoculum which is applied either as a top dressing or incorporated into topsoil. The microbes present in jeevamrutha helps to make the nutrients non-available form to dissolved form when it is inoculated to the soil. It also helps as antagonism to pathogens. PGPR, cyanobacteria, PSB, Mycorrhizal fungi and Nitrogen fixing bacteria or some important microbes present in this product. It provides nutrients, microbial population and helps to prevent bacterial and fungal diseases. It requires only first 3 cycles after that system that self-sustaining.

3. Acchadana/ Mulching: Mulching is of 3 types followed, they are straw mulch, soil mulch and live mulch. Dry crop residues applied as an amendment to the soil surface (paddy straw, groundnut husks etc.), or cover crops (often legumes). So that the growth of cover crops like legumes helps in reduce the weed population and increases the water infiltration capacity. However, their root nodules fix the atmospheric Nitrogen into the soil which helps in nitrogen supply to crops. From these residues retention on the surface of the soil increases the microbial degradation processes and liberation of nitrogen from nitrification. It also supplies organic matter to the soil which contain many micro and macro nutrients. It improves seed germination without soil ploughing.

4. Whapasa-aeration: In soil, out of soil mineral and organic matter, there is an equal proportion of water and air present. If higher amount of water makes the plant suffers from oxygen deficiency and it may lead to cause death of plants except water loving plants like rice. The soil aeration also an important parameter to plant growth so application interval should be longer.

Advantages of Natural Farming

1.Improved Soil Health

Natural farming focuses on building and maintaining healthy soil through practices like composting, mulching, and crop rotation. These methods enhance soil fertility, structure, and moisture retention, leading to better long-term productivity.

2. Reduced Chemical Use

Natural farming avoids synthetic pesticides, herbicides, and fertilizers. This reduces the chemical load on the environment, protecting water sources, wildlife, and beneficial insects like pollinators.

3. Biodiversity Conservation

By encouraging a diverse range of crops and maintaining natural ecosystems, natural farming fosters biodiversity. This supports a healthy balance

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of plant and animal life, which can help control pests naturally and increase resilience to diseases.

4. Lower Carbon Footprint

Practices like reducing synthetic fertilizer use and increasing soil carbon sequestration help in reducing the overall carbon footprint. Natural farming also often involves energy-efficient farming methods, which are less reliant on fossil fuels.

5. Water Conservation

Natural farming techniques improve soil structure and water retention, reducing the need for excessive irrigation. This can be particularly beneficial in water-scarce regions, where water conservation is critical.

6. Resilience to Climate Change

Natural farming methods help increase the resilience of crops to extreme weather conditions, such as droughts or heavy rains, by building more robust ecosystems and improving soil health.

7. Cost Savings

While transitioning to natural farming can require an initial investment, it often reduces costs in the long run. There's less reliance on expensive chemical inputs (pesticides, fertilizers), and methods like composting and using cover crops can often replace these costs.

8. Healthier Food

By avoiding chemical pesticides and fertilizers, natural farming produces food that may be healthier for consumers. Additionally, the emphasis on diverse, organic crops leads to more nutrient-rich produce.

9. Enhanced Farm Resilience

A system based on natural farming principles is often more resilient to pests and diseases because it emphasizes diversity, healthy soil, and ecological balance. This means fewer losses and a more sustainable farm in the long term.

10. Connection to Nature

Farmers practicing natural farming often develop a closer connection to the land and the ecosystems they manage. This can lead to greater satisfaction and a more fulfilling relationship with their work.

11. Net economic impact

The direct benefits are- reduced costs of cultivation, higher yield, lower costs of borrowing, gain income from intercrops, and a slightly higher selling price. In addition to this, the social and environmental benefits are food, nutrition, and health security, employment, soil health, and water security, coastal ecosystem regeneration, climate resilience, biodiversity protection, and less risk.

Constraints in natural farming

- Shifting from conventional farming practices to natural farming can be challenging.
- The labour requirement is increased compared to conventional farming.
- The demand for animal manure is high. On a national scale, the number of cattle in India could not support this level of manure application.
- Demand and consumption pattern constantly changing when it comes to high-value products.
- There is no value of natural products in large scale areas even the price also similar to chemically produced products. Hybrid varieties, not permitted-continuously increasing global population food is scarce to all.
- Populations. Even by using chemicals, we are not reaching our food production target, without hybrids, it is impossible to reach the target.
- Pest management is difficult- different crop-specific weeds, diseases, insects are damaging to crop drastically; by using natural products its control is not satisfactory to farmer's level.
- Quality planting material and other proven techniques like GMO’s are not considered.
- Non-availability of indigenous cow, it contains Millions of beneficial microbes and pathogen-free dung.

- Development of a package of practices of all crops- there is no specific package of practices to crops grown under natural farming.
- Non-availability of commercial formulations- naturally formed growth stimulants, pest control Astras are not available on large scale, and its storage life is less no longer keep this product and not available in local markets.

Conclusion:

However, the practices were found to be very cheap and effective in improving the soil microbial status i.e. bacteria, fungi and actinomycetes, which might help in sustainable crop production and ecological balance in the long term by improved nutrient transformation and availability. The natural farming practices need to be tested for their influence on crops, soils and ecosystems in long-term experiments.

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Cotton leaf curl virus; A devastating disease of cotton

Aakash and Pooja
Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana

Cotton leaf curl virus (CLCuV) is a significant viral threat to cotton plants. It falls under the genus Begomovirus within the family Geminiviridae. The main vector responsible for its transmission is the whitefly, particularly the species *Bemisia tabaci.* CLCuV poses a major threat to cotton production in many regions, particularly in South Asia and Africa, where it has caused substantial economic losses. Efforts to control the virus often involve integrated pest management strategies, including the use of resistant cultivars, insecticides to manage whitefly populations, and cultural practices to reduce virus reservoirs.

Cotton leaf curl virus (CLCuV) pose a significant impact on cotton production in India, particularly in the northern states where cotton is a major crop. Here are some key points regarding the losses caused by CLCuV in India:

1. Economic Impact: India's cotton growers have suffered significant financial losses as a result of CLCuV outbreaks. Growers' revenues are negatively impacted by the virus, which lowers cotton yields and lowers the quality of the fiber.
2. Yield Reduction: Infected plants typically exhibit symptoms such as leaf curling, vein swelling, and yellowing of leaves, which can significantly reduce the productivity of cotton fields. Yield losses can vary depending on factors such as the severity of the virus infection, the susceptibility of cotton varieties, and the effectiveness of control measures implemented.
3. Regional Impact: In the northern Indian states of Punjab, Haryana, Rajasthan, and parts of Uttar Pradesh, where cotton

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production is common, CLCuV has been especially problematic. The virus has frequently broken out in these areas, posing constant challenges for cotton growers.

4. Management Challenges: Managing CLCuV in India has been challenging due to various factors, including the rapid spread of the virus, the development of insecticide resistance in whitefly populations, and limited availability of resistant cotton varieties. Farmers often resort to intensive insecticide applications to control whitefly vectors, which can further exacerbate environmental and health concerns.
5. Research and Interventions: Research on resistant cotton cultivars, integrated pest management techniques, and public awareness programs to inform farmers of the significance of early identification and control measures have all been part of India's efforts against CLCuV. Potential biotechnological interventions have also been investigated, such as genetic engineering for virus resistance.

Overall, CLCuV continues to pose a significant challenge to cotton production in India, highlighting the importance of ongoing research, collaboration among stakeholders, and sustainable management practices to mitigate its impact on agricultural livelihoods.

The virus causes characteristic symptoms including leaf curling, vein swelling, and yellowing of leaves, which can severely impact the yield and quality of cotton crops. It can also infect other plants in the Malvaceae family, such as okra and hibiscus. Major symptoms are:

1. Leaf Curling: One of the most prominent symptoms is the upward curling or rolling of leaves, often along the margins. This curling can be severe, leading to distorted leaf shapes.
2. Vein Swelling: Infected leaves may exhibit swelling or thickening along the veins, which can give the leaves a puckered or wrinkled appearance.
3. Leaf Yellowing: Yellowing or chlorosis of the leaves is another common symptom of CLCuV infection. This yellowing typically starts at the margins or tips of leaves and may progress to affect the entire leaf surface.
4. Stunted Growth: Infected plants often exhibit stunted growth, with reduced internode length and overall smaller plant size compared to healthy plants.
5. Mosaic Patterns: In some cases, infected leaves may exhibit mosaic patterns of light and dark green areas, which can vary in intensity and distribution across the leaf surface.
6. Leaf Necrosis: Severe CLCuV infections can cause necrosis or tissue death in affected leaves, leading to the formation of brown or black lesions.

Leaf curling

Cotton leaf curl virus (CLCuV) has had a significant impact on cotton production in India, particularly in the northern states where cotton is a major crop. Here are some key points regarding the losses caused by CLCuV in India. Overall, CLCuV continues to pose a significant challenge to cotton production in India, highlighting the importance of ongoing research, collaboration among stakeholders, and sustainable management practices to mitigate its impact on agricultural livelihoods.

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Mosaic patterns

The management of Cotton Leaf Curl Virus (CLCuV) involves a combination of preventive, cultural, chemical, and biological control measures. Here's an overview of various management strategies:

1. Use of Resistant Varieties: One of the best ways to manage CLCuV is to plant cotton cultivars that are resistant or tolerant. Plant breeders create genetically resistant cotton varieties to lessen the effect of infection on crop quality and productivity. Whenever feasible, farmers should select and grow these resistant types.
2. Vector Control: Managing whitefly populations is essential since whiteflies (*Bemisia tabaci*) are the primary vector of CLCuV. Biological control agents, cultural practices, and pesticides are all able to achieve this. Integrated pest management (IPM) tactics are frequently the most successful since they include different control measures.
3. Insecticide Application: Using insecticides can help manage whitefly populations and lower the spread of viruses. On the other hand, overuse of pesticides can damage beneficial insects and cause whitefly populations to become resistant. As a result, it's necessary to apply pesticides carefully and in accordance with established recommendations.
4. Cultural Practices: The spread of CLCuV can be slowed down by cultural measures such as weed control, crop rotation, and the removal of contaminated plants. Minimizing virus transmission can be achieved by eliminating weeds that act as whitefly reservoirs and other potential hosts for the virus.
5. Early Detection and Monitoring: For the purpose of early identification and prompt intervention, cotton fields must be routinely inspected for signs of CLCuV and whitefly infestations. Farmers who detect the virus early can put control measures in place before it spreads widely.
6. Biological Control: Whitefly populations can be suppressed with the aid of biological control agents, such as predatory insects and parasitoid wasps, which are naturally occurring enemies of whiteflies. Biological control combined with habitat management and conservation can serve as a supplementary strategy for controlling other pests.
7. Resistance Management: To prevent the development of resistance in whitefly populations, it's important to rotate insecticides with different modes of action and use them in combination with other control methods. Resistance monitoring and implementing resistance management strategies are essential components of sustainable pest management.
8. Public Awareness and Extension: Educating farmers about CLCuV, its symptoms, and effective management strategies through extension programs and farmer training sessions can improve awareness and adoption of best practices.

By integrating these management strategies and implementing them in a coordinated manner, growers can minimize the impact of CLCuV on cotton production and promote sustainable pest management practices. Ongoing research and collaboration among scientists, extension services, and farmers are essential for developing and refining effective management approaches.

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Molecular weapons of a soldier fighting against a virus

Bhavya Chidambara
UAS, GKVK, Bengaluru, and ICAR IIHR Hessaraghatta

Background of the war

Enemies never cease to exist for any independent and successful individuals, and plants being self-reliant but sessile are no exception. It's inevitable for plant life to be ready for war declared by any of its enemies, be it bacteria, fungi, viruses, or other microorganisms. Let me narrate a popular war story of a virus and its host, it's about a Tomato (Scientifically called *Solanum lycopersicum*) and one of the greatest parasitic enemies- ***Tomato leaf curl virus*** **(ToLCV)** belonging to a big family 'Geminiviridea' and an important member of a group called 'Begomovirus'. Don't think that as the name indicates it will infect only tomatoes, it infects other plants like brinjal, potatoes, tobacco, beans, peppers, etc.

Do you know? If invaded, this virus makes the plants sterile if it infects at an early stage of plant growth. Plant fails to bear flowers, if at all managed to flower, fruit set will not take place, and the plant looks short-statured with upward curled leaves. You should know this, just like a dengue fever spread by mosquitoes, this leaf curl virus is spread to other plants by an insect called whitefly (SN: *Bemisia tabaci*). To avoid the infection, the plants are sprayed with insecticides to kill whiteflies, which is not a smart option because of various reasons. Similar to how some mosquitoes can't be managed by using repellents or killer sprays, these whiteflies also can't be controlled by using chemical pesticides. Another concern is that pesticide residues on marketed fruits and the trend of 'go organic' compels the alternative solution to these problems. One such solution is the use of resistant plants as planting material, but we have very few resistant plants that have been commercialized.

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You know? Some people are resistant to mosquitoes, I mean few people do not prefer mosquitoes. Reasons might be body odor, temperature, and blood type of humans that makes them repel mosquitoes. Similarly, in tomato plants, it's been reported that few wild tomato plants are resistant to these whiteflies or ToLCV. In plants, it's possible to transfer the resistance from wild plants to cultivated plants using crossing (a process known as 'breeding'). Once you identify a resistant plant you can cross it with a commercial one then harvest the first-generation seeds for sowing in the field. But it's not that easy because some wild lines are not compatible with cultivated tomato plants for reproduction. Now because of the advanced breeding tools it is possible to cross the incompatibility barrier and transfer resistance to other plants using genetic engineering. It is possible only when you know the exact mechanism of resistance in plant systems at 'the molecular level'. This opportunity has invoked an interest among research scientists across the globe to work on molecular aspects of how the resistance is building up only in particular plant individuals (soldier plants).

Identifying soldier plant

In my PhD research, I have asked a question, what are the important molecular weapons that resistant plants (soldier plants) are pooling to fight against ToLCV? For that, I have taken the challenge of identifying a wild plant that is resistant to ToLCV among 28 wild tomato plants. I have made the whiteflies carrying ToLCV to feed on individual plants of all 28 wild plant species, this allows the whitefly to inject ToLCV into all the plants. After 10 days the symptoms started appearing in susceptible plants but the resistant ones stood unaffected and with no symptoms even after 21 days. Among the 28 suspected wild tomato plants, 11 were found strong enough to fight back against the virus, but here I have to tell you that not all wild plants will survive in field conditions for several reasons. Only four plants belonging to three different wild species namely *S. piminellifolium, S. peruvianum, and S. lycopersicum* survived. I chose this ***S. peruvianum* soldier** for my further study of how this plant is defending itself against viruses. And what are all the powerful weapons in its possessions?

Soldiers are ready with weapons to fight with virus

Let us first understand the normal life of plants at the molecular level. To understand functioning at the molecular level, first, we have to consider plants at the cell level, which is the basic unit of life. In simple words, the whole information required for life to happen is coded in DNA form which is then copied to RNA form as and when required by the cell for growth, development, and '**defense**'. This Xerox mechanism is highly monitored to avoid mistakes. The RNAs are of two kinds, coding (Those that translate into proteins) and non-coding (those that regulate the translation process), again both kinds have different types of RNA. Here for our understanding, I will consider only three types of RNA from both, mRNA (messenger RNA) which acts as a template for protein synthesis, second one miRNA (microRNA) which controls the translation of some mRNAs into protein and finally CircRNA (Circular RNA) which perform various function but importantly sponging of the second RNA I mentioned that is miRNA. Even though we are at the infant stage of understanding all the functional aspects and complexity of how different kinds of RNAs coordinate together to regulate the information relay from DNA to RNA and RNA to protein, through which the cell controls exactly the whole thing called life.

CircRNA is a diverse and unique family of non-coding RNAs found in plant cells, abundant in the eukaryotic transcriptome, their discovery and identification of functional involvement in biological processes has opened up a new way of looking at how genomic regions interact in numerous ways. However, their particular role still needs to be understood. The majority of circRNAs are conserved throughout species and often exhibit differential expression depending on tissue or developmental

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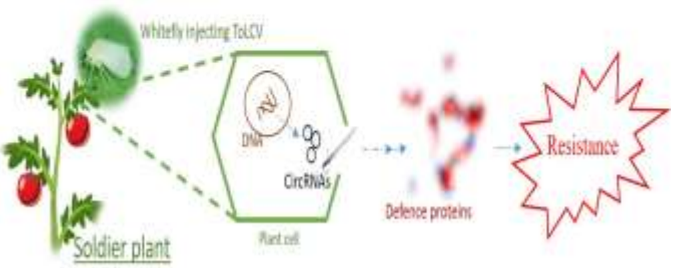
stage and **response against diseases**. **RNA sequencing** (Knowing the presence of specific RNA and their copy number in a particular cell type at a given time) helps in identifying circRNA and their target RNAs (Parent genes) and, in turn, their role in a given situation.

What I did to understand the role of plant CircRNA in fighting against the ToLCV is that I made the whiteflies infect a set of resistant (*S. peruvianum)* plants. I also raised a set of control plants (without virus infection). Isolated the RNA from both sets at different intervals (After infection). These RNA are pooled separately as infected and control RNA and sequenced to determine all the specific circRNAs made by resistant plants to be involved in a war against the virus. Several circRNAs were produced specifically in resistant plants and they were involved in controlling the expression of specific RNAs involved in disease resistance. Among them, two CircRNA (with parent genes: Solyc02g080530.3 and Solyc02g088950.2) were controlling the production of their parent genes POD and SOD (defense-responsive proteins). This I have validated with the biochemical analysis of the proteins POD and SOD, where it was proved that these proteins were in higher quantity in infected resistant plants compared to control plants.



Hypothetical illustration of soldier plant defense against ToLCV

Our study of identifying circRNAs in resistant plants for ToLCV is the first of its kind in tomatoes and we hypothesized that these circRNAs must be acting as mi-RNA sponges and positively regulating their parental genes. Further, we are working towards finding the actual mechanism of this circRNA during viral infection and resistance against the virus which can be a potential tool to target specific plant viral diseases using genomic approaches like genetic engineering.

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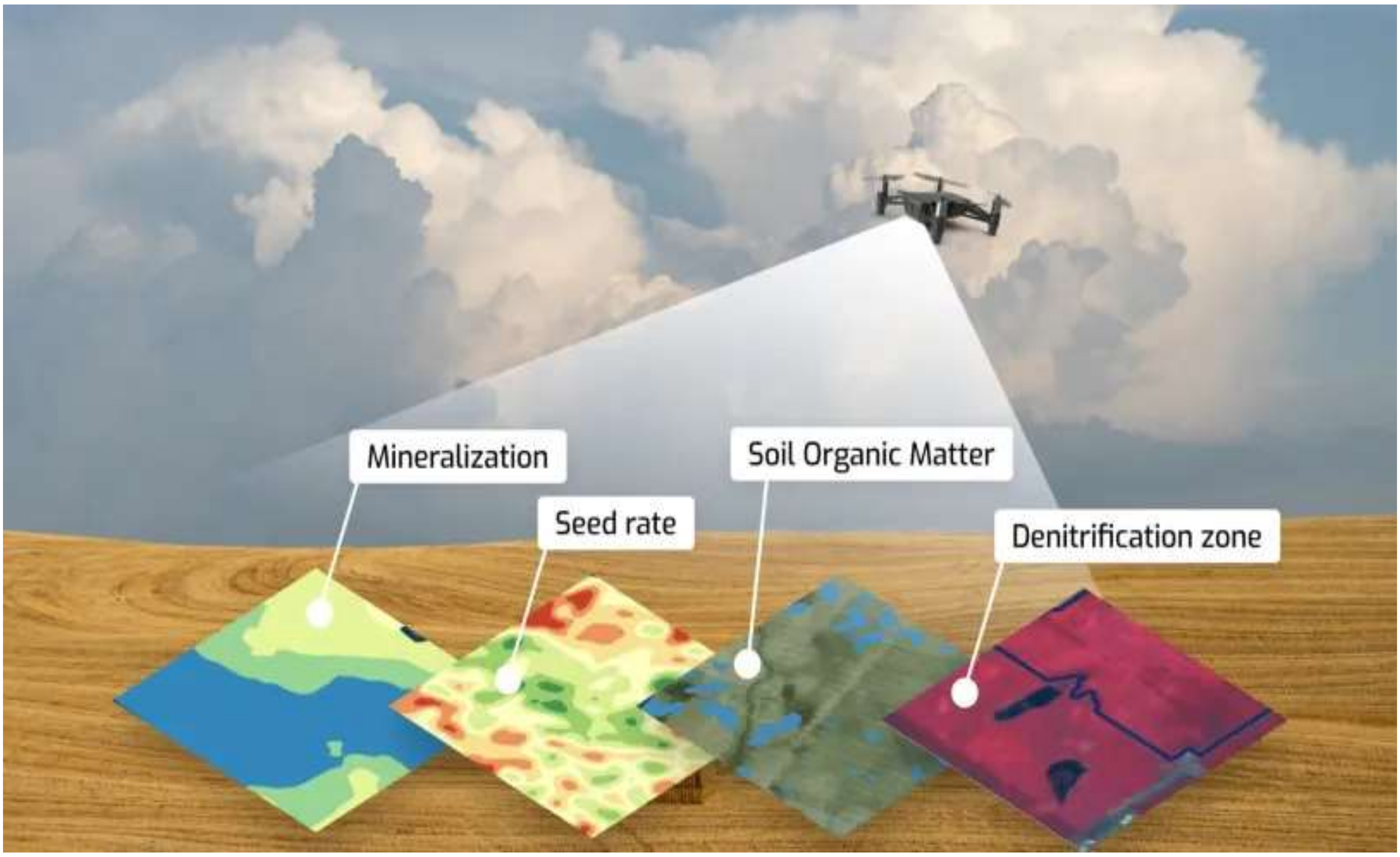

Digital Soil Mapping: The new frontier in Precision Agriculture

Dr. Akhila Merin Mathew[1] and Dr. Goutham Suresh S. P[2]

[1]Ph.D (Soil Science), [2]Ph.D (Olericulture)

Digital Soil Mapping (DSM) is a modern approach in soil science that combines traditional soil survey techniques with advanced computing technologies to create and update spatial soil information systems. It involves using field and laboratory observations along with spatial and nonspatial soil inference systems. Essentially, DSM utilizes environmental data, quantitative methods, geographic information science, and cartography within a framework to predict soil classes and properties across a landscape. This allows for the creation of soil maps at a finer degree of resolution and covering more extensive areas than traditional methods.

The development and adoption of precision agriculture technologies have created a significant demand for the detailed soil information provided by DSM. Precision agriculture enables farmers to apply crop inputs, such as seeds and fertilizers, at variable rates tailored to specific locations within a field, often at a resolution of one meter or less. This site-specific management aims to optimize resource use, improve crop yields, and minimize environmental impacts. However, the effectiveness of these precision technologies is often limited by the resolution and accuracy of currently available soil maps, which traditionally were created at coarser scales.

DSM directly addresses this limitation by providing more accurate and detailed spatial information on soil properties like organic carbon, cation exchange capacity, bulk density, pH, and nutrient content. By understanding the spatial variability of these soil attributes at a high resolution, precision agriculture practices can be significantly enhanced. For instance, DSM can inform:

- Variable rate application of fertilizers and amendments: Tailoring nutrient inputs based on the specific fertility levels identified by detailed soil maps.
- Precise seed placement: Adjusting planting density according to soil type and conditions to optimize germination and growth.
- Targeted irrigation management: Applying water based on the soil's water-holding capacity and drainage characteristics mapped through DSM.
- Improved land use decisions: Matching crop selection and management practices to the inherent capabilities and limitations of different soil areas within a field.

Furthermore, the ability of DSM to integrate with machine learning allows for the development of predictive correlations between soils and their properties with various uses and climatic changes. This is crucial for adapting agricultural practices to evolving environmental conditions and for promoting sustainable land management. The improved accuracy offered by DSM techniques, such as incorporating neighborhood effects of environmental covariates, and the focus on mapping soil properties throughout the complete soil profile, offer a more nuanced and effective approach to supporting the goals of precision agriculture.

Digital Soil Mapping (DSM) techniques involve:

- Utilizing Environmental Covariates (ECs) derived from various sources such as remote sensing data, Digital Elevation Models (DEMs), geological maps, and land use maps to predict soil properties.
- Employing Statistical Modeling, including traditional methods like Multiple Linear Regression (MLR) and Partial Least Squares Regression (PLSR), as well as more advanced techniques like Gaussian Process Regression (GPR).
- Applying Geostatistical Approaches such as kriging (including ordinary kriging and regression kriging) to account for the spatial dependence of soil properties.
- Leveraging Machine Learning (ML) Algorithms like Random Forest (RF), Support Vector Machines (SVM), and Artificial Neural Networks (ANN) for predicting and classifying soil attributes.
- Incorporating Spatial Context by considering the neighborhood effects of environmental covariates to enhance mapping accuracy.

Some field level examples of digital soil mapping are:

- Enhanced Soil Property Mapping Accuracy: DSM, using advanced techniques like incorporating neighborhood effects of environmental covariates, has significantly improved the accuracy of mapping soil properties such as organic carbon and pH.
- Precision Agriculture Improvement: Projects are using DSM to create high-resolution soil maps and databases to enable more precise application of agricultural inputs, aiming to improve yields and efficiency.
- Climate Change Impact Assessment: DSM is being used to develop predictive models for climate change impacts on soils, including changes in carbon stocks and the distribution of soil issues like salinity.
- Revolutionizing Farming Methods: Detailed soil knowledge from advanced mapping techniques (akin to DSM) is helping to develop targeted farming methods to address specific soil challenges and boost crop yields in regions like China.
- Improving National Soil Surveys: DSM techniques are being adopted to create more precise and actionable national soil survey data.
- Creating Practical Soil Fertility Maps: DSM is used to generate soil fertility maps based on detailed soil profile data, aiding in better management of fertilizers and amendments.

- Addressing Lowland Soil Characteristics: DSM is increasingly applied in lowland agricultural areas to map soil variables like salinity and organic carbon using various environmental data and machine learning

Digital Soil Mapping (DSM) is a major step forward in soil science, offering detailed and spatially precise insights into soil properties that surpass traditional, less refined approaches. By utilizing various environmental data and advanced analytical methods, DSM greatly improves our knowledge of how soil varies across different terrains, including agricultural lowlands. This enhanced understanding of soil is essential for smart and precision farming, allowing for targeted application of resources and optimized management at specific locations, ultimately leading to better crop production. Moreover, DSM is vital for tackling critical issues like climate change by supporting climate-smart agricultural practices and enabling the monitoring of soil carbon and degradation. In essence, the detailed and dynamic soil maps created through DSM equip land managers, policy creators, and scientists with the information needed to make better choices for sustainable land use, environmental protection, and ensuring a secure food supply.

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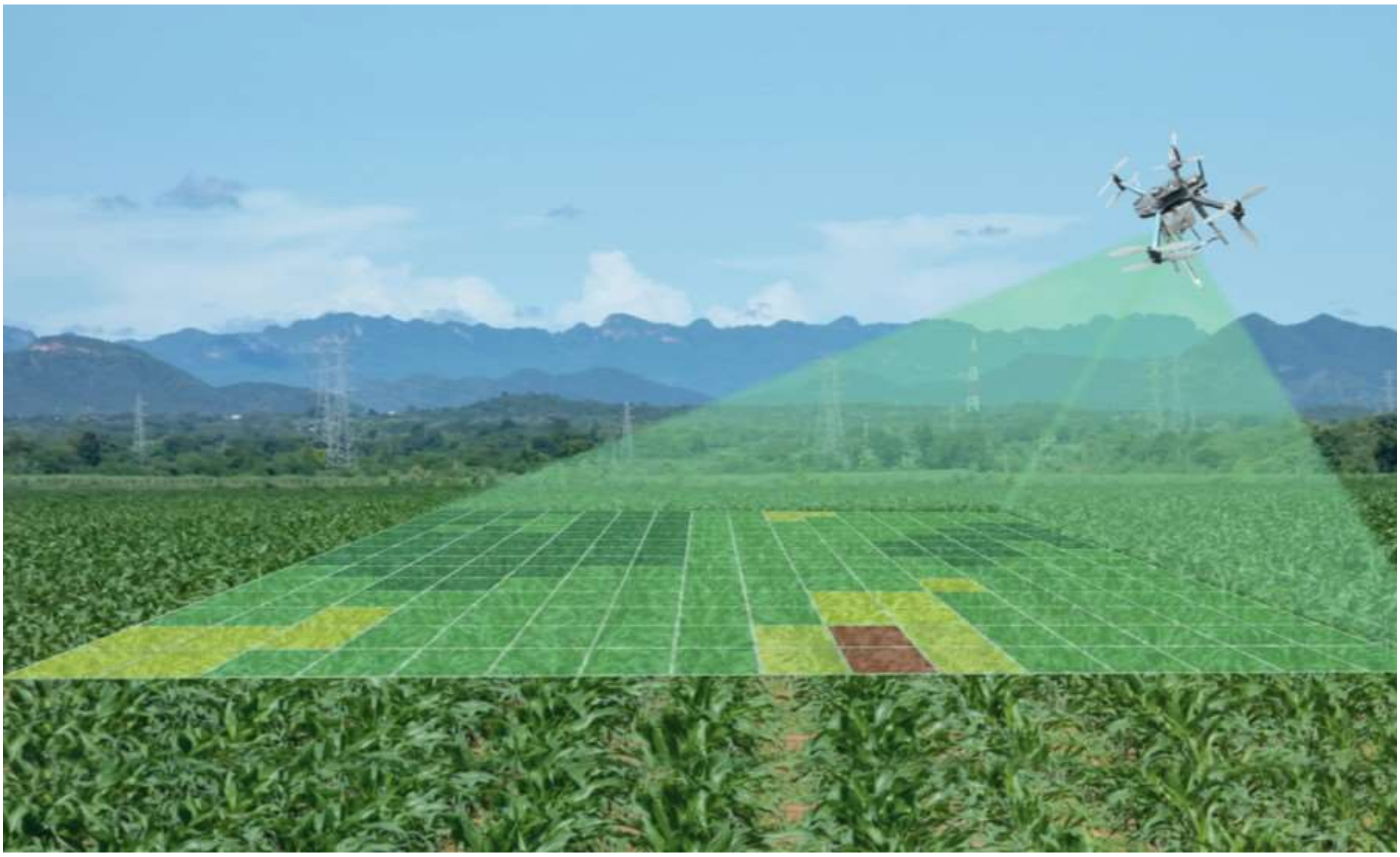

Remote Sensing and GIS - Agriculture and Natural Resource Management

Shivam Pandey
Project Scientist, Remote Sensing Applications Centre U.P. Lucknow

Agriculture plays a vital role in every nation's economy. It represents a substantial trading industry for an economically strong country. Remote sensing and Geographic information systems used to analyze and visualize agricultural environments has proved to be very beneficial to the farming community as well as industry.

Overview of the application of remote sensing and geographic information systems in agriculture and natural resource management. Reliable and timely information on types of crops grown, their area and expected yield is importance for the government for an agriculturally based country. Applications of different remote sensing techniques are important for crop monitoring, crop condition assessment and yield estimation for the sustainability of agriculture and natural resources. The spectral information is an important aspect of remote sensing data for crop modeling, and it is strongly related with canopy parameters, which are representative of crop health and crop growth stages. Remote sensing and GIS can also be used very effectively in land use/land cover analysis as well as damage assessment because of drought, floods and other extreme weather events. Information on meteorology and vegetation is the two major important inputs into agricultural meteorology. Applications of remote sensing technologies are an important and effective method to identify pest-infested and disease. It is one of the effective tools for assessing and monitoring the water resources.

Applications of remote sensing in agriculture include major important things such as biomass and yield estimation, vegetation vigor and drought stress monitoring, assessment of crop phenological development, crop acreage estimation and cropland mapping, mapping of disturbances and land use land cover changes, in addition to precision agriculture and irrigation management. GIS based mapping application can help to identify location of crops growing across the country and to adapt different variables, monitor the health of individual crops, estimate yields from a given field, and maximize crop production. By using land-use and primary food crop statistics, along with data collected by different tools, including mobile devices able to identify areas in need and underlying causes of food insecurity, GIS is instrumental in the efforts to end global hunger, and it is an integral part of automated field operations

Remote sensing (RS) and Geographical Information System (GIS) play a crucial role in the identification of crops and areas where changes in cropping patterns and are useful tools to carry out crop surveys and mapping. Reliable and timely information on types of crops grown, their area and expected yield is important for the government for an agriculturally based country. The spectral information is an important aspect of remote sensing data for crop modeling and it is strongly related with canopy parameters which are representative of crop health and crop growth stages. Crop-specific maps created by combining satellite image, survey data and provide the layout of the land and owners (farmers) which are helpful to agribusinesses such as seed and fertilizer companies. The science of remote sensing can play a significant role in inventorying data base on different crops. Several studies using aerial photographs and digital image processing techniques have been reported in literature. It helps in reducing the amount of field data to be collected and provides higher precision of the estimate

Applications of Remote Sensing in Agriculture:-

Remote sensing technology has found numerous applications in fields like forestry, geology, surveying, and photography. However, the use of remote sensing in agriculture is where it has been found most useful. Some of the many applications of agriculture and remote sensing include the following.

1. Observing and monitoring crops /Crop Production

A critical role of remote sensing in agriculture is monitoring the health of crops. Optical (VIR) sensing allows one to see beyond visible wavelengths, like infrared; in this case, the wavelengths are very sensitive to crop vigor, damage, and stress. Recent advances in this technology have allowed farmers to observe their fields and make timely crop management decisions. Crop identification using remote sensing also helps identify crops affected by conditions related to weather, pests, etc.

During the early days, the data of remote sensing focused on land covers and crop types, but now its focus is on biophysical characterization of plants. Remote sensing technology has potential to estimate crop productivity based on crop and soil biophysical attributes. The data obtained from remote sensing may be used for estimating crop production. This technique reduces the labor cost and improves precision agriculture.

2. Observing soil conditions/ Soil and Land Agricultural Mapping:-

For precision agriculture, monitoring the soil is essential. Some critical soil parameters to optimize crop management include soil organic matter (SOM), soil texture, soil pH level, moisture content, etc. Remote sensing technology in agriculture will also provide canopy health, growth stage, yield, biomass, and vegetative density. If you want to investigate the crop growth pattern changes, you need to emphasize the link between crop performance and soil conditions.

Agricultural land resource maps are very diverse, ranging from land maps as basic data to thematic maps derived from them. In the 1980s, for surveying and compiling land maps, aerial photographs were interpreted manually using a three-dimensional stereoscope against overlapping aerial photographs (mosaic). Land use and cover in aerial photographs can be used as a marker of soil formation and soil type. Technological advances have produced a variety of images with varying detail and accuracy, ranging from Landsat images suitable for review-scale map preparation (1:250,000 scale) or SPOT images for more detailed scale (1:50,000 scale or greater). Various maps can be made from soil maps, such as land suitability map, commodity recommendation map, agro-ecological zone (AEZ) map, commodity zoning map, land management recommendation map and so on. In addition, satellite images are used to create maps of paddy fields and other land uses, such as oil palm, coconut, sugar cane, and cocoa plantations. It can also identify land availability maps, swamp land map types and agricultural land conversion.

3. Monitoring water conditions

Due to population growth and food demand, it is expected that irrigated lands will double by 2050. It will decrease water availability, contribute to climate change, and cause other environmental changes. Hence, monitoring and assessing agricultural water resources are critical to achieving sustainable food security and development. Remote sensing in precision farming has successfully provided accurate and timely information, like water bodies, irrigated cropland, crop and soil water status, and various scales.

4. Predicting weather conditions

Climate and weather data systems are essential if you want to make crop management decisions and schedule irrigation. Additionally, this data can also help you prepare against natural disasters. This application of remote sensing in precision farming has provided spatial coverage to predict upcoming weather conditions successfully. With this data's help, you will be provided better predictions of crop needs and help cut down unwanted costs.

5. Observing air quality

Different types of crops thrive in different air conditions. Some may do well against windy air conditions, while others are more suited for calmer environments. Remote sensing in plant protection has allowed us to determine air conditions in specific locations. This data can help you predict upcoming air conditions to take the necessary precautions in case of unfavorable weather conditions.

6. Precision farming

The introduction of new farming techniques in the last few decades has helped agriculture keep pace with the increasing population's food demand. Precision farming and crop mapping using remote sensing aim to increase the yield of the crops and minimize strain on the natural environment. Modern technologies like AI or the Internet of Things have proved to be useful in this aspect. Remote sensing uses in agriculture have also been used to increase the productivity of the crops.

7. Monitoring and predicting climate changes

The remote sensing concept and application in agriculture has provided a lot of advances when it comes to an understanding of climatic changes by quantifying the temporal states of the oceans, land, and atmosphere. While technologies could detect weather and climatic changes, there were not as precise as this one. When it comes to farming and agriculture, weather plays an important role and will determine the yield results. Hence, this technology has proved to be a valuable tool for making accurate climate change predictions.

8. Assessment of Field Condition

Remote sensing plays a significant role in assessing the plant heath by using bio- physical indicators. Many physiological changes occur in crops due to various stresses and the same can be detected and recorded by remote sensing. Monitoring of drought by using remote sensing is used and accepted. Moreover, VCI (Vegetation Condition Index) and NDVI (Normalized Difference Vegetation Index) is also utilized to identify the drought conditions in field.

9. Optimizing Agricultural Inputs

The most important role of remote sensing is precision agriculture which helps to optimize the water and nutrients in field. Identifying the need of

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particular nutrient and need of water at the critical crop growth period helps to reduce production cost and improve water and fertilizer use efficiency. In areas where drought occurs, drip irrigation along with remote sensing improves the crop production and reduces the inputs. Under a wet environment, nitrogen fertilizer leaches more due to variation in water content, SOM content and yield. These conditions cause TSF (traditional single-rate N fertilization) failures.

10. Estimating Crop Production

Remote sensing is an innovative way to forecast crop yield by finding a relationship between vegetation indices and yield. The crop yield is dependent on many factors such as variety, soil type, weather, pests and diseases. The spectral response of remote sensing is dependent on all these factors.

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Efficient Utilization of Available Water for Sustaining Crop Productivity

Madhukar R. More[1] and Suyog B. Khose[2]

1. Professor (CAS), Department of SWCE, VNMKV Parbhani-431 402 (M.S.)
2. PhD Scholar, Indian Institute of Technology Kharagpur, 721302 (West Bengal)

Water holds the potential to be a source of peace or a trigger for conflict. Its scarcity, pollution, or unequal distribution can deepen divisions within communities and escalate tensions between countries. As climate change intensifies and populations grow, the need for collective action to conserve and equitably manage this vital resource becomes ever more urgent. Public health, food and energy security, economic productivity, and ecological integrity all depend on a stable and well-managed water cycle. Cooperation over water can generate a powerful ripple effect fostering harmony, supporting sustainable development, and strengthening resilience to shared global challenges. Water is not merely a resource to be exploited or competed over it is a fundamental human right, intimately tied to dignity, health, and survival. On this World Water Day, let us unite around water's power to foster peace and lay the foundation for a more stable, equitable, and prosperous future.

Water scarcity is a growing global challenge, disproportionately affecting the poorest and most vulnerable. As terrestrial water reserves—stored in soil, snow, and ice—continue to diminish, water becomes more unpredictable, placing additional stress on social systems. Women, girls, and marginalized communities bear the brunt of this crisis, often facing increased workloads, reduced access to education or livelihoods, and heightened risks to their safety. Addressing water scarcity through inclusive and cooperative strategies is not just a matter of sustainability, it is a path toward

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social justice and global stability. As nations face the interconnected pressures of climate change, migration, and political unrest, putting water cooperation at the heart of decision-making is essential to building a resilient future for all.

Maharashtra, with a total geographical area of 307.71 thousand square kilometres, is divided into the Godavari, Krishna, Tapi, Narmada, and Konkan basins. The state experiences significant variability in rainfall, leading to uneven water availability across regions. Annually, Maharashtra extracts approximately 15.91 billion cubic meters of groundwater for irrigation and 1.04 billion cubic meters for domestic and industrial purposes. This extensive use places Maharashtra fourth among Indian states in terms of groundwater extraction, following Uttar Pradesh, Punjab, and Madhya Pradesh. Groundwater plays a critical role in the state's agriculture, supporting over 50 percent of the total irrigated area. However, the expansion of irrigation without assessing groundwater availability has resulted in the uncontrolled drilling of bore wells, causing increasing pressure on groundwater resources.

According to a joint report by the Central Groundwater Board and the Groundwater Survey and Development Authority, Maharashtra has an estimated net groundwater availability of 32,152 million cubic meters, with about half already being utilized for irrigation, drinking, and industrial use. As per central government guidelines, groundwater extraction should not exceed 70 percent of the total annual availability to ensure sustainability. However, continued over-extraction threatens to significantly lower groundwater levels. The situation is further exacerbated by insufficient efforts toward groundwater recharge. While groundwater usage remains a priority, initiatives to replenish it lag behind, deepening the water table across many regions. This is particularly alarming as 90 percent of the rural population depends on groundwater for drinking, highlighting the urgent need for a balanced approach to both extraction and recharge for long-term water security.

Agriculture in Maharashtra is predominantly rain-fed and highly dependent on seasonal rainfall, which is often irregular and insufficient. Out of the total 225.7 lakh hectares of cultivated land, approximately 82% is arable, while only around 18% falls under irrigated agriculture. A significant constraint to irrigation in the state is its geology—around 82% of Maharashtra's land area is underlain by hard rock formations, which have limited groundwater availability. These rocks can hold only 1 to 4 percent of water relative to their total volume, compared to 5 to 10 percent in alluvial or sedimentary formations. Despite this limitation, the state has approximately 19 lakh irrigation wells and 2 lakh bore wells, reflecting a growing dependence on groundwater for agriculture.

However, groundwater is a finite resource, and its excessive extraction has raised serious concerns. In many villages, more emphasis is placed on groundwater withdrawal than on recharge efforts, contributing to a rapid decline in water tables. This situation is further aggravated by the widespread cultivation of water-intensive crops, especially in areas already experiencing high levels of groundwater extraction. Traditional irrigation methods, which are less efficient, continue to be used for such crops, further accelerating the depletion of groundwater. As a result, not only is agricultural sustainability at risk, but drinking water sources are also being adversely affected.

How we conserve rainwater is ultimately more important than how much of it falls. In Maharashtra, soil and water conservation efforts carried out under the Watershed Development Program, along with proper water planning, have demonstrated that even areas receiving below-average rainfall can remain green provided water is managed wisely. This is evident in the few villages with well-developed watersheds that continue to thrive despite limited rainfall. However, such examples are rare and countable. There remains a critical misunderstanding about groundwater many fail to realize that it is not naturally present in the soil but accumulates over time from rainwater that seeps underground. The prevailing mind-set that those who have access to groundwater can use it freely, without concern for others, is both dangerous and contrary to the principles of nature. Nature distributes resources equitably, and to align with this balance, some difficult yet necessary decisions must be made to ensure fair access to drinking water and water for livestock. While such changes may face resistance initially, they will yield long-term benefits.

Sustainable groundwater conservation is a shared responsibility, and everyone must contribute to protecting this vital resource.

If the soil has low organic matter content, it becomes prone to cracking under water stress. These cracks allow moisture from deeper layers to escape through evaporation, and any water applied to crops often seeps through the cracks beyond the root zone, making it unavailable to the plants. However, cultivating such land through timely weeding, hoeing, and applying organic mulch can help seal the cracks, enhance irrigation efficiency, and conserve valuable water. Different crops have varying water needs depending on their type, and choosing suitable varieties can greatly reduce irrigation demands. One effective method for preserving soil moisture is mulching, which minimizes evaporation losses. Mulch can be made from polythene film or organic materials such as dried grass, wood chips, sugarcane husks, straw, wheat or rice straw, and mountain ash. If available, polythene film of 80–100 microns thickness is ideal. For fruit trees, a 4 to 6-inch layer of organic mulch should be placed around the drip line where fibrous roots are most active. To prevent the risk of fungal diseases like powdery mildew, Folidol powder should be dusted before applying mulch. In addition to conserving moisture, organic mulch also helps improve soil structure and fertility, contributing to healthier crop growth and long-term sustainability.

Water conservation can be significantly improved by adopting simple yet effective practices. For instance, shading nurseries and one- to two-year-old fruit tree saplings using small structures slightly taller than the plants helps reduce water wastage. Similarly, planting windbreak trees such as Shevari, Subabul, Suri, and Nilgiri around orchards slows down wind velocity, which in turn reduces evaporation from the soil and plant surfaces. Ponds, too, are vulnerable to evaporation due to heat. To address this, certain commercially available chemicals can be applied to the pond's surface to form a thin layer that reduces evaporation.

However, it is crucial to ensure that such treatments do not affect water quality or obstruct irrigation systems. Alternatively, covering ponds with shade nets, ranging from 50% to 90% shading capacity, installed at a height of one to one and a half meters, can also significantly reduce evaporation while preventing the growth of moss. Therefore, conservation methods that work in one village may not necessarily succeed in another. Soil and water conservation strategies must be tailored to local conditions. Implementing comprehensive watershed development measures typically takes 3–4 years, and once completed, their upkeep becomes the responsibility of the local community. Active public participation plays a vital role in both the construction and long-term maintenance of these initiatives. Villages where people are actively involved in these efforts often witness greater success.

Today, it is essential for everyone to take responsibility not only for meeting their daily water requirements but also for securing water for agriculture. Whether the support comes from government funding, community contributions, or donor assistance, it must be utilized efficiently for the development and management of water resources. Only through such collective efforts can we move towards creating a water-secure Maharashtra.

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Soil Health Card: A Promising Initiative Yet to Gain Traction

Ramijur Rahman
Department of Soil Science, Assam Agricultural University, Jorhat, Assam, India

The Soil Health Card (SHC) scheme, launched by the Government of India in 2015, aims to promote sustainable soil management by providing farmers with essential information on soil fertility and nutrient status. It helps optimize fertilizer use, reduce costs, and enhance productivity. However, the scheme faces challenges such as limited farmer awareness, inadequate soil testing infrastructure, and inconsistent adoption of recommendations. While SHC has led to reduced fertilizer misuse and increased micronutrient application, its reach remains restricted. Strengthening the program through improved laboratory facilities, better farmer outreach, and policy reforms—such as integrating a Soil Health Index will ensure greater effectiveness. Addressing these challenges will lead to long-term soil health and improved agricultural sustainability.

Introduction

With the increasing population Worldwide and in India, farmers are more prone to intensive farming practices, utilizing agricultural soil to meet the food requirements of the rising population. To achieve higher yields, they often apply tremendous amounts of synthetic fertilizers without understanding the actual condition and requirements of the soil. This not only rises cost of production of agricultural produces but additionally depleting soil fertility, disrupts the soil ecosystem and affecting the long-time period of agricultural sustainability. Soil assessment plays an essential function in addressing these troubles by means of knowing insights into soil fitness, availability of nutrient and vital amendments for soil. By evaluating soil conditions often, farmers can optimize fertilizer use, reduce pointless input costs, enhances productivity, and maintain soil health for future generations by way of making sure sustainable and green farming practices.

Keeping these things in mind, the Government of India has undertaken an initiative called the Soil Health Card (SHC) to promote balanced fertilization and sustainable soil management. On 19th of February, 2015, Ministry of Agriculture and Farmers' Welfare (Government of India) launched Soil Health Card Scheme in India with the moto "Swasth Dharaa. Khet Haraa (Healthy Earth. Green Farm)". The Soil Health Card (SHC) is a comprehensive report that provides a detailed assessment of soil quality based on 12 key parameters. These include macronutrients such as nitrogen (N), phosphorus (P), and potassium (K); the secondary nutrient sulfur (S); and essential micronutrients like zinc (Zn), iron (Fe), copper (Cu), manganese (Mn), and boron (Bo). Additionally, it evaluates crucial physical and chemical properties, including soil pH, electrical conductivity (EC), and organic carbon (OC). Based on this analysis, the SHC offers specific recommendations for fertilizer application and necessary soil amendments, helping farmers optimize nutrient management and improve soil fertility for sustainable agricultural productivity.

Key Features of the Soil Health Card

- The government aims to extend the benefits of this scheme to all farmers across the country.
- The initiative is designed to cover every region, ensuring nationwide implementation.
- Farmers will receive a Soil Health Card, which provides a detailed report on the condition of their farm's soil.
- Each farm will be assessed, and a new Soil Health Card will be issued every three years.

Benefits of the Soil Health Card Scheme

- Farmers will have a detailed record of their soil health, helping them understand proper soil management practices. With this knowledge, they can make informed decisions about future crop planning and land utilization.
- The Soil Health Card will provide farmers with insights into nutrient deficiencies in their soil, guiding them on suitable crops to cultivate and the appropriate fertilizers to use. As a result, this will lead to improved crop yield and better farm productivity.

Soil Testing Facilities

Soil samples are analyzed following approved standards for all 12 designated parameters through various authorized laboratories. Testing is conducted at Soil Testing Laboratories (STLs) owned by the Department of Agriculture, either by their own staff or by personnel from outsourced agencies. Additionally, analysis takes place at STLs fully operated by outsourced agencies. Institutions under the Indian Council of Agricultural Research (ICAR), including Krishi Vigyan Kendras (KVKs) and State Agricultural Universities (SAUs), also contribute to soil testing. Furthermore, soil assessments are carried out in the laboratories of Science Colleges and Universities, where students perform tests under the supervision of professors or scientists, ensuring both academic learning and quality control. In 2022–23, the Soil Health Card (SHC) scheme was integrated into the Rashtriya Krishi Vikas Yojana (RKVY) under the 'Soil Health & Fertility' component. To enhance efficiency, technological advancements were introduced in 2023, including a mobile application with GIS integration and a QR code-based system for tracking soil samples.

Reach of Soil Health Card

According to the Economic Survey, the agriculture sector in India serves as a livelihood source for approximately 42.3% of the population and contributes 18.2% to the country's GDP at current market prices (PIB, 2024). 80 % of the total population of India is associated with small and marginal farming practices out of 1.27 billion population as of 2017-18 (FAO). Although the PM-KISAN scheme launched by GOI in the year 2019 is

Awareness about SHC Scheme (in %)

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widely recognized among farmers, awareness about the Soil Health Card (SHC) scheme remains significantly low which has been launched a long 10 years ago. Many farmers are either unaware of its existence or lack sufficient knowledge about its benefits. In the Fig. 1, percentage of awareness is represented. As a result, they continue to rely on excessive fertilizer use without understanding their soil's actual nutrient requirements, leading to soil degradation and increased production costs.

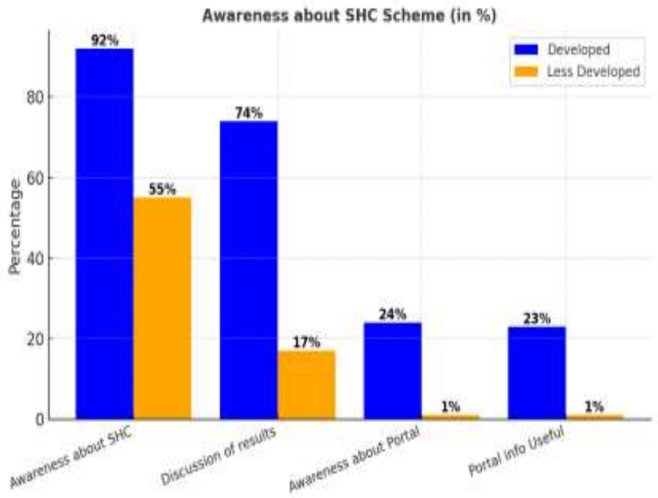

Fig.1: Percentage of awareness about SHCC in India
(Source: MANAGE: Impact Study of Soil Health Card Scheme)

As of 2025, India's population is almost 140 crores out of which 112 crores of population's source of income is agriculture and livestock production relied mostly as small and marginal farmers. The lack of awareness about the Soil Health Card (SHC) Scheme among farmers can be attributed to its limited reach, with knowledge primarily confined to academicians, students, administrators, and a small segment of well-informed farmers. As a result, a vast majority of farmers remain unaware of the scheme's potential benefits, hindering its widespread adoption.

According to MoAFW, a total of 24.74 crore Soil Health Cards have been generated over the past 10 years. Fig. 2 represents the cards generated in the year 2024-25. However, this figure includes multiple issuances to the same farmers, as the scheme provides updated soil health assessments every three years. Consequently, the actual number of unique beneficiaries may be lower than the total reported cards. Over the past few years, the Soil Health Card generation has increased at an average rate of 60% to 80%. However, the exact number of newly enrolled farmers remains unclear, as the reported figures include repeated issuances to the same participants. Accurate tracking of unique beneficiaries is essential to assess the scheme's true impact and reach.

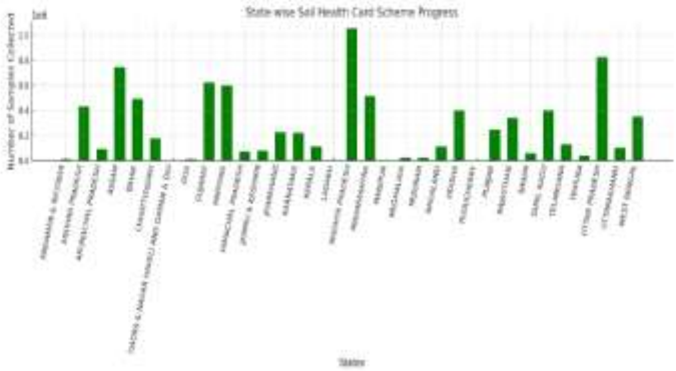

Fig. 2: State wise test completed and SHC generated in the Year 2024-25
(Source: https://soilhealth.dac.gov.in/soil-health-dashboard)

Moreover, The Soil Health Card (SHC) scheme has positively impacted farmers, with about 66% understanding its content, 57% finding the recommendations suitable, and 53% successfully implementing them. The scheme is inclusive, with small and marginal farmers actively adopting the suggested practices. A notable outcome has been a 20–30% reduction in the use of urea and DAP for paddy and cotton in some states, leading to a cost-saving of Rs. 1,000 to Rs. 4,000 per acre. Additionally, there has been a slight increase in the application of micronutrients, particularly gypsum, after the distribution of SHCs. Farmers who followed the prescribed recommendations observed a significant increase in yield. The combined effect of lower input costs and improved productivity has led to higher net incomes for farmers, demonstrating the effectiveness of SHCs in promoting sustainable agricultural practices while enhancing profitability and soil health in the long run (MoAFW, 2024)

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Implementation Challenges

India has established nearly 8300 soil testing laboratories since 2014-15 (MoAFW), but only 45 % of them are equipped to analyze micronutrients. Although agricultural departments have recently procured around 7,000 mobile testing kits, these kits do not match the efficiency and accuracy of fully equipped laboratories. Moreover, only a limited number of labs can conduct micronutrient analysis due to a lack of skilled personnel, necessary chemicals, and functional equipment. Given that the scheme aims to benefit 112 crore farmers, the existing infrastructure remains highly inadequate and falls short of meeting the nationwide demand for comprehensive soil testing. Strengthening laboratory facilities and investing in capacity building are crucial to ensuring the effective implementation of soil health assessment programs.

Literacy levels among farmers have been identified as a critical factor affecting the utilization of Soil Health Cards. Limited awareness among small and marginal farmers remains a significant hurdle, as many are unfamiliar with the benefits and proper utilization of soil health reports. Inadequate laboratory infrastructure, including outdated equipment and a shortage of skilled technicians, often leads to delays in soil testing and the timely dissemination of results. Furthermore, logistical issues, such as inefficient sample collection and processing, further hinder the scheme's efficiency. Additionally, the adoption rate of SHC recommendations varies across regions due to socio-economic disparities, differences in literacy levels, and insufficient extension services. Some farmers also perceive soil testing as an additional burden rather than a benefit, reducing participation rates. Addressing these challenges through targeted awareness campaigns, improved infrastructure, and better advisory services is crucial for maximizing the scheme's impact on sustainable soil management.

Policy Improvement and Future Prospects

The Soil Health Card (SHC) program holds immense potential for improving soil quality and ensuring sustainable agriculture. To enhance its effectiveness, a Soil Health Index should be developed and integrated into SHC, classifying soils into Grade-A, B, and C, with periodic updates incentivizing farmers to improve soil quality. Linking SHC data with Aadhaar and making it accessible through e-seva portals will enhance transparency and policy integration. Rationalizing fertilizer subsidies by reducing support for NPK while promoting micronutrients, bio-fertilizers, and organic inputs will encourage balanced fertilizer use. Establishing state-of-the-art accredited labs for testing soil quality and ensuring high standards of input supply is crucial. Farmer Producer Companies (FPCs) should be engaged in SHC implementation by stocking and supplying recommended soil amendments. Incentives should be provided to farmers and local bodies promoting sustainable practices like green manure, crop residue recycling, and crop rotation with legumes. Technological advancements, such as neem-coated urea and reduced bag sizes, can minimize excessive fertilizer use. Additionally, policies related to water and electricity should align with soil conservation goals to promote crop diversification. Strengthening the SHC program through these improvements will lead to healthier soils, increased productivity, and long-term agricultural sustainability.

Summary

The Soil Health Card scheme is a promising initiative for sustainable agriculture, but its impact is limited by low awareness and inadequate infrastructure. Strengthening soil testing facilities, increasing farmer engagement, and aligning policies with soil conservation are essential for success. Integrating a Soil Health Index and leveraging technology will enhance its effectiveness, ensuring long-term soil health and improved agricultural productivity.

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The Future of Farming: Climate-Smart Agriculture for a Sustainable Tomorrow

Dr. Rajat Mishra[1*], Dr. Vikas Singh[1], Dr. Kaushal Kumar[2]& Dr. Sarvesh Kumar[2]
[1]Teaching Associate, Department of Soil Conservation & Water Management, CSAUAT, UP-208002
[2]Professor, Department of Soil Conservation & Water Management, CSAUAT, UP-208002

Asasa Climate change poses a significant challenge to global food security. Rising temperatures, erratic rainfall, and increasing frequency of extreme weather events threaten agricultural productivity. In response, Climate-Smart Agriculture (CSA) has emerged as a strategic approach to enhance resilience, improve productivity, and reduce greenhouse gas emissions. CSA integrates innovative practices, policies, and technologies to ensure sustainable agricultural systems. Greenhouses and polyhouses play a crucial role in achieving these objectives by creating controlled environments for crop production.

Types of Climate-Smart Agriculture

1. **Conservation Agriculture:** Minimal soil disturbance, crop rotation, and cover cropping to maintain soil health and water retention.
2. **Agroforestry:** Integrating trees and shrubs into farming systems to enhance carbon sequestration and biodiversity.
3. **Precision Farming:** Use of sensors, drones, and AI-driven analytics to optimize water, fertilizer, and pesticide usage.
4. **Climate-Resilient Crop Varieties:** Development of drought-resistant and heat-tolerant crop varieties through genetic improvements.
5. **Integrated Pest and Nutrient Management:** Efficient use of bio-pesticides, organic fertilizers, and balanced

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nutrient application to enhance productivity and sustainability.

6. **Water-Efficient Irrigation Systems:** Drip irrigation, rainwater harvesting, and controlled irrigation practices to optimize water usage.
7. **Hydroponics & Aeroponics:** Soil-less farming techniques to save water and nutrients.

Current Status of Climate-Smart Agriculture

The adoption of CSA varies across regions. While developed nations have integrated high-tech solutions into their farming practices, developing countries are gradually transitioning towards CSA with the help of government policies and international support. Global initiatives such as the FAO's CSA program and the Global Alliance for Climate-Smart Agriculture (GACSA) are actively promoting CSA strategies worldwide.

Figure: *Protected cultivation, Precision Farming and IOT integration*

Indian Scenario

India, with its diverse agro-climatic conditions, faces numerous challenges related to climate change. Several government initiatives, including the National Adaptation Fund for Climate Change (NAFCC) and Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), support CSA practices. Farmers are increasingly adopting organic farming, zero-tillage techniques, and micro-irrigation systems to enhance sustainability. However, widespread adoption is hindered by financial constraints, lack of awareness, and limited access to technology.

Global Scenario

Several countries have made significant progress in implementing CSA. The Netherlands has pioneered precision agriculture and vertical farming to maximize productivity with minimal environmental impact. African nations, under the **Comprehensive Africa Agriculture Development Programme (CAADP)**, are integrating CSA techniques to address food security and climate challenges. The United States and Australia are investing heavily in **digital agriculture**, leveraging big data and AI to enhance farm efficiency and climate resilience.

Future Prospects

The future of CSA lies in technological advancements and policy support. Key areas of focus include:

- **AI and IoT in Agriculture:** Real-time monitoring and predictive analytics for efficient resource management.
- **Carbon Farming and Soil Health Improvement:** Encouraging farmers to adopt carbon sequestration techniques.
- **Sustainable Livestock Management:** Reducing methane emissions through improved feed and breeding practices.
- **Public-Private Partnerships:** Encouraging collaborations for research, funding, and farmer training programs.

Conclusion

Climate-Smart Agriculture is not just a necessity but a crucial pathway to securing global food production in the face of climate change. While challenges remain, continued investment, policy support, and farmer engagement will drive the transformation towards a more resilient and sustainable agricultural system. Greenhouses and polyhouses, when integrated with climate-smart practices, can significantly enhance food security while mitigating climate change impacts. Investments in sustainable technologies and farmer training will be key to scaling up these solutions. The integration of CSA practices is vital for ensuring food security while mitigating the adverse effects of climate change on agriculture.

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Establishment and maintenance of balled and burlapped trees

Logeshwaran Kandasamy[1], Shakila Sadasivam[2], Mohamed Rizwan T I[1]

[1]PG Scholar, [2]Asst. Prof. -*Department of Floriculture and Landscaping, SRM College of Agricultural Sciences, Chengalpattu -603201, Tamil Nadu*

Introduction

Tree transplanting is a big business venture in the floriculture sector. Trees are a significant component in landscaping. The act of relocating an established tree from one location to another is called Burlapping. Tree transplantation often necessitates the removal of a significant number of roots due to the vast structure and form of the tree root system. Individual trees that are in danger of being felled, destroyed, or damaged can be preserved, maintained, or salvaged by the ancient practice of tree transplanting. In upscale building projects with sufficient commercial or green historical significance, it is increasingly common to transplant elder trees upright, where the entire canopy may be kept without pruning or bending. Trees weighing fifty kilograms to fifty tons can be transplanted with precaution to maintain their graciousness and charm. This strategy of tree conservation is commonly used in cosmopolitan cities like Delhi, Hyderabad, Chandigarh, and Noida to develop quick vegetation and to improve the atmospheric air quality. Although transplanting trees is much costlier than planting saplings, factors including plant size, age, and aesthetic value are crucial. The methods and steps of balling and burlapping are emphasized for the sustainability of the landscape.

Balled and Burlapped Trees

The Balled and Burlapped trees (B&B) are found in nurseries and come in a variety of sizes. It can be planted over a longer period of time than bare-root transplants and require less maintenance.

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Hydraulic spades or manual labor can be used to dig up B&B trees. It is simple to modify the root ball's shape to accommodate unique planting circumstances, such as high water tables or compacted soils. On an average, 95% of the tree's original root system remains in the field. Larger trees require more expensive shipping due to the weight of the soil, handling and specialized equipments.

Steps in Balling technique

The trees to be transplanted are thoroughly watered and dug out using a hydraulic tree transplanter (Fig. 1a). The root ball must be carefully covered with a soft fabric container called burlap, as the roots are brittle and prone to dry once removed from the soil (Fig.1b).

Fig. 1a Hydraulic tree transplanter (Source: Qwart, 2024)

The process of covering the root ball with a fabric material is called as balling. Trees removed must be immediately taken to the planting location or watered thoroughly kept away from sun and wind to prevent water loss. Watering should be done regularly until the planting is completed.

Fig. 1b Soft fabric containers or burlap for covering root of trees (Source: Svetlana Monyakava, 2019; Tiffany Selvey, 2024)

Steps in Burlapping technique

Burlapping is the process of transplanting meaning removal of the fabric material from the root ball and planting the trees in the desired location.

Preparation of planting hole and transplanting:

- The planting hole should be at least three times as large as the root ball and slope of must be provides both sides.
- Place the trees two inches above the surrounding ground to give the root ball time to settle and prevent water from ponding at the base of the tree. If the tree has bare roots, roots must be spread out before backfilling, to avoid girdling.
- Remove burlap from the sides and planting has to be done.
- The roots of the tree may not be able to grow because synthetic burlap rots in the soil very slowly or not at all. While the, natural burlap will break down.
- Backfill with original soil to avoid changes in soil pore diameters and do not add any amendments.

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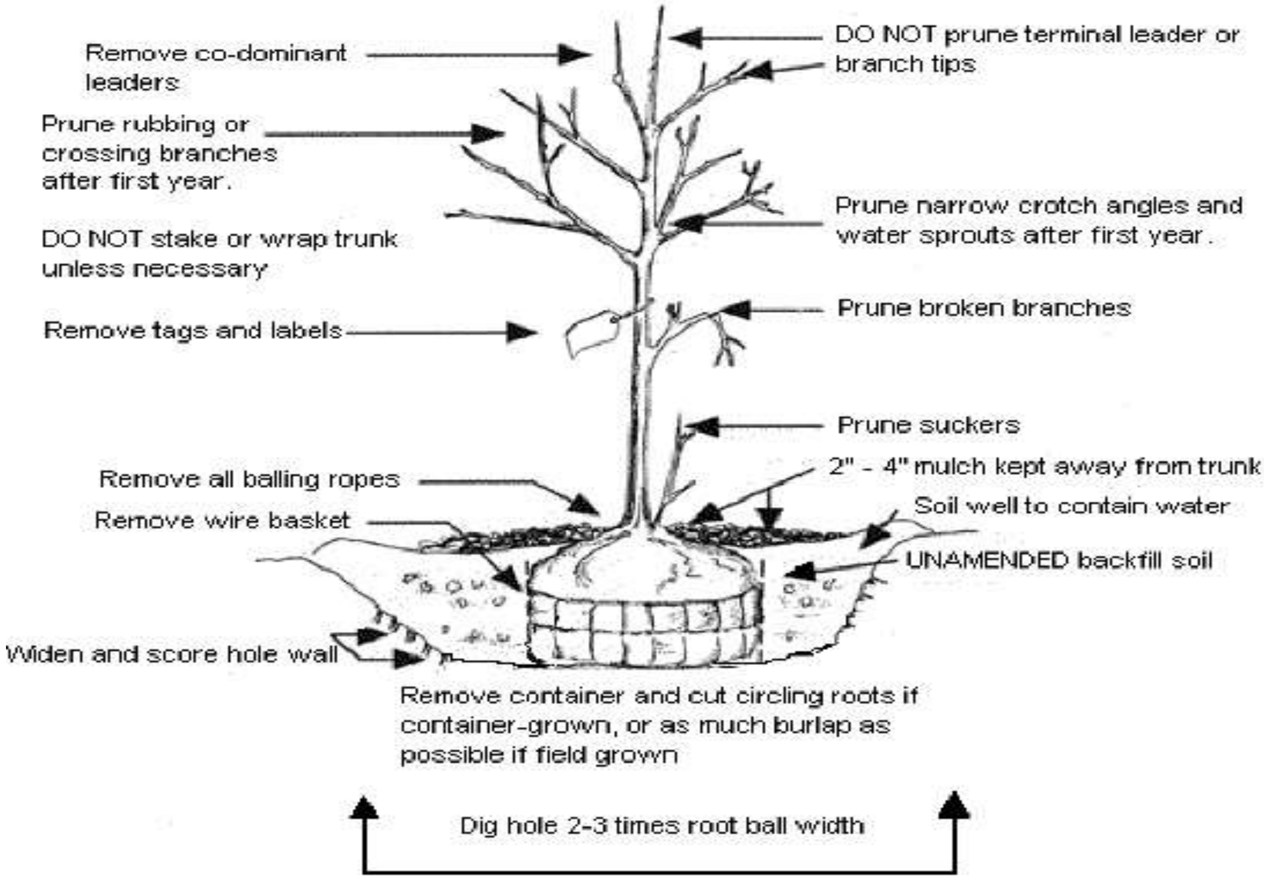
- Watering can be done halfway through planting and after backfilling.

Until the plants have completely acclimatized to the transplanted location.



Source: *Appleton and French, 1995*

Post-transplant handling

Following a transplant, proper care will increase the livelihood of survival, reduce stress, and increase the success rate. The transplanted tree takes roughly 30 to 45 days to produce new branches and foliage. Transplanted trees are under stress until the root systems are completely acclimatized. To recover the trees from shock, the following maintenance & care should be given.

1. Watering

Watering must be done on planting day. During first year, trees should be watered weekly depending on the species chosen. From the second year, watering should be done once in 2 weeks (or) 2 weeks interval during summer and monthly once during spring and winter. From the third year, a transplanted tree has to be watered once in a month irrespective of season.

2. Mulching

Immediately after transplanting the entire root zone must be covered with organic mulch at 1 – 3 inches. Piling mulch around the trunk may cause the wood to rot and make the tree susceptible to disease and insect infestation. Place the mulch 4-6 inches away from the main bark. Mulch will naturally break down and decompose, so it may need to be reapplied within 12-18 months.

3. Fertilizer Application

Fertilizer is not advisable for a newly transplanted tree. Until a nutrient shortfall is verified, fertilization might not be required. During the initial establishment stage, a moderate release of nutrients from the breakdown of mulch and organic matter placed to backfill soil may be adequate.

4. Staking and pruning

Staking is done to keep the root ball intact and cup a weak & their trunk upright. Trees with a trunk diameter of more than 1.5 inches does not require staking. Large trees require staking as the plants may break &root ball will be moved due to wind. Staking may be necessary for smaller trees until sufficient trunk strength is developed.

Pruning is not required until 2 years of transplanting. Broken branches should also be removed, avoid over-pruning to make up for root loss.

Trees suitable for Burlapping

S. No.	Common name	Botanical name	Family
1	Ashoka tree	*Saraca asoca*	Fabaceae
2	Gulmohar	*Delonix regia*	Fabaceae
3	Copper pod tree	*Peltophorum pterocarpum*	Fabaceae
4	Mahua tree	*Madhuca longifolia*	Sapotaceae
5	Arjun tree	*Terminalia arjuna*	Combretaceae
6	Red silk-cotton tree	*Bombax ceiba*	Malvaceae
7	Foxtail palm	*Wodyetia bifurcata*	Palmae
8	Pungam tree	*Pongamia pinnata*	Fabaceae
9	Wild areca palm	*Areca triandra*	Palmae
10	Fishtail palm	*Caryota urens*	Palmae
11	Tailpot palm	*Corypha umbraculifera*	Palmae
12	Cabbage palm	*Corypha utan*	Palmae
13	Triangle palm	*Dypsis decaryi*	Palmae
14	Areca palm	*Dypsis lutescens*	Palmae
15	Indian doum palm	*Hyphaene dichotoma*	Palmae
16	Ribbon fan palm	*Livistona decora*	Palmae
17	Fiji fan palm	*Pritchardia pacifia*	Palmae
18	Lady palm	*Raphis excelsa*	Palmae
19	Royal palm	*Roystonea regia*	Palmae
20	Jacaranda	*Jacaranda mimosifolia*	Bignoniaceae

Conclusion

In 2024, burlapping is an investment in the long-term health and vibrancy of environment, not merely a precaution. As climate resilience becomes increasingly imperative in landscape planning, the meticulous care of B&B trees represents not merely an aesthetic concern but a tangible contribution to environmental sustainability and ecological function within both managed and naturalized landscapes. In conclusion, the establishment and maintenance of balled and burlapped (B&B) trees represents a critical intersection of horticultural science and environmental sustainability.

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Optimizing Rice (Oryza sativa) Growth Under Nutrient Stress in Hydroponics System

Snehasree Samanta and Debobrata Dey
Department of Genetics and Plant Breeding, Ramakrishna Mission Vivekananda Educational and Research Institute, West Bengal, India

Rice (*Oryza sativa*), a dietary staple for over half of the world's population, faces significant cultivation challenges stemming from nutrient deficiencies, water scarcity, and the impacts of climate change. Traditional soil-based systems are often unable to supply adequate macro- and micronutrients, ultimately limiting crop productivity. In this context Hydroponics emerges as a sustainable, soil-less alternative by allowing precise nutrient management to optimize rice growth under controlled conditions. It also outlines the morphological, physiological, and biochemical adaptive mechanisms rice plants employ to cope with nutrient stress. Further, it highlights the significance of root architecture modifications, symbiotic microbial interactions, and the role of acid phosphatase and anthocyanin accumulation under stress conditions. The hydroponic approach enhances nutrient uptake efficiency, minimizes environmental impact, and offers potential solutions for urban and land-limited farming. Although limitations such as high initial investment and the need for technical expertise persist, hydroponics represents a forward-looking strategy to improve rice productivity and facilitate the development of climate-resilient, nutrient-efficient varieties capable of meeting global food demands.

Introduction

Rice (*Oryza sativa*) is the most widely consumed food crop in Asia, serving as a staple for approximately 50% of the global population and about 34.5% of the Indian population. Globally, around 500 to 700 million tonnes of paddy rice are produced and consumed annually. As a staple crop, rice is not only central to food security but also plays

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a vital role in providing livelihoods, supporting economic growth, and maintaining social stability for billions of people. Rice cultivation occurs in diverse ecosystems categorized based on soil water availability, including irrigated lowland, irrigated upland, rainfed lowland, rainfed upland, and deep-water ecosystems. Approximately 75% of global rice cultivation is through transplanted systems in flooded conditions, while the remaining 25% is direct-seeded. However, transplanted rice systems face several critical challenges, such as water scarcity, deficiencies in macro- and micronutrients, methane emissions contributing to greenhouse gases, and various biotic and abiotic stresses, all of which significantly reduce productivity. Enhancing rice productivity amid climate change and rapid population growth is a major agricultural challenge. Rice requires sixteen essential nutrients, among which nitrogen (N), phosphorus (P), and potassium (K) the primary macronutrients are particularly important for plant growth, yield, physiological development, metabolic processes, and stress resistance. However, low nutrient availability in soils, often due to the fixation of nutrients by inorganic and mineral compounds, poses a significant barrier to achieving optimal yields.

To overcome these limitations, hydroponics a soil-less cultivation system is emerging as a sustainable solution. In hydroponics, rice plants are grown in a balanced nutrient solution tailored to each developmental stage, ensuring enhanced nutrient availability and uptake. This method not only increases nutrient use efficiency but also enables the development of climate-resilient and nutrient-efficient rice varieties, thereby offering a promising approach for sustainable productivity in the face of environmental challenges.

Rice cultivation in hydroponic: A sustainable approach

Traditional puddled transplanted rice cultivation is highly resource-demanding and a major contributor to greenhouse gas emissions. In this context, hydroponics a soil-less, nutrient solution-based farming technique offers a sustainable and efficient alternative for rice cultivation. While hydroponics has gained momentum in global agriculture, its adoption in India remains limited due to high initial investment costs, technical complexity, and lack of awareness among farmers. Introduced in India in 1946 by W.J. Shalto Douglas and further explored during the 1960s and 70s, hydroponics is still evolving within Indian agriculture. However, the potential of rice hydroponics is immense. It allows precise control of water, nutrients, and environmental factors, resulting in improved nutrient use efficiency, reduced pest and disease incidence, and higher yields. Moreover, hydroponics supports climate-resilient agriculture by minimizing the carbon footprint, reducing land use, and enabling urban and vertical farming in land-scarce regions. It aligns with the principles of a circular economy by emphasizing resource recycling and sustainability. Research is ongoing to adapt traditional rice varieties to hydroponic systems by simulating submerged conditions and optimizing root development under varying nutrient regimes. Despite current limitations, rice hydroponics holds promise for transforming Indian agriculture by integrating modern technology with sustainable practices. It offers a viable solution for increasing rice productivity, ensuring food and nutritional security, and adapting to future agricultural demands under environmental stress. With the right policy support, technological innovations, and farmer education, hydroponics can become a game changer for rice cultivation in India, paving the way toward a resilient, high-yielding, and resource-efficient future.

Role of essential nutrient in rice physiology and deficiency symptoms

Nutrients are essential for optimal plant growth and development. Every nutrient have their own character and involved different metabolic and enzymatic activity to regulate plant life cycle. The deficiency of nutrients may cause chlorosis, necrosis and stunted growth that eventually cause significant crop losses. Nutrient effect tolerance to crop against different Pest, diseases and pathogen.

a) **Nitrogen**: The main ingredient in soil organic matter that is necessary for rice growth and maximum yield is nitrogen, which is also found in amino acids, proteins, nucleic acids, and chlorophyll. A key factor in raising rice output is photosynthesis. Rice has the highest photosynthetic nitrogen utilization efficiency (NUE) of any C3 plant, meaning that it absorbs a lot of photosynthesis at the leaf level, which boosts growth, yield, tillering, grain filling, and protein synthesis. When nitrogen is not present, rice leaves turn light green and chlorotic at the tips, becoming short and upright with a lemony yellow hue, and the tiller becomes smaller.

b) **Phosphorous**: Phosphorous is also a essential nutrient for diveresed metabolic and physiological process encompassing energy metabolism, cell division, DNA synthesis and phospholipid biosynthesis as a phosphate (Pi) or pi esters .it is responsible for the development of root ripening early flowering tolerances to different biotic and abiotic stress in rice. Phosphorous use efficiency (PUE) in rice only 25% and show obvious symptoms when suffering phosphorous deficiency as stunted growth, reduced tillering, narrow and short dark green leaves, fewer panicles and grains, and thin stems Additionally, delays the flowering and maturity by one week to 20 days. In severe conditions, plants may not flower at all and even if they flower, a large number of empty grains are formed with poor quality. Plants have evolved various morphological, physiological, and biochemical adaptive mechanism to acquire P from the soil, particularly under P-deficiency conditions.

c) **Potassium:** After nitrogen, potassium is one of the most vital nutrients for rice cultivation. It plays a key role in reinforcing vascular bundle lignification under flooded conditions, enhancing plant Vigor, supporting cell division, and buffering organic acids. Potassium is also associated with the lignification of sclerenchyma cells, which contributes to improved resistance against lodging. Deficiency symptoms include chlorosis marked by orange or yellowing leaves, particularly at the margins of lower leaves, along with stunted growth. A lack of potassium leads to smaller, lighter rice grains and ultimately results in significant yield reduction.

d) **Zinc**: One of the intrigal rice micronutrient available in Zn^{++}, $ZnCl^{+}$, ZnO. Zinc at as a cofactor for enzyme like glutamate dehydrogenase and alcohol dehydrogenase involved in N metabolism. A zinc shortage substantially reduced ability of rice seedlings to withstand anaerobic soil conditions, decreases anaerobic root metabolism, and inhibits alcohol dehydrogenase function. At the Early stages of growth, a rice plants are most vulnerable to zinc deficiency. If the deficit is not treated, it may also affect crops during the reproductive growth stage. The earliest phases of zinc shortage in the youngest plants are characterized by chlorotic leaf bases because zinc is not very mobile throughout the plant.

e) **Iron:** Iron (Fe) play a crucial role in rice photosynthesis. Also, component of various enzyme cytochromes, catalases, dipeptides, etc. At the early seedling stage show deficiency symptoms due to its immobile in nature. The initiation of Fe deficiency is identified with interveinal yellowing and chlorosis of developing plants. The advancement of Fe deficiency contributes to a standardized pale-yellow appearance with bleached appearances.

f) **Boron**: Boron is essential for the development of new meristematic cells and plays a vital role in flower formation, pollen germination, and cation absorption. It is crucial for cell wall biosynthesis and maintaining cell membrane integrity. A deficiency in boron often leads to poor pollen viability, negatively affecting reproductive success. Visible deficiency symptoms typically appear as white, rolled leaf tips in young plants,

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g) resulting from the limited mobility of boron, which prevents its translocation to new growing tissues.

Adaptive mechanism exhibit in rice under nutrient deficiency

Rice plants undergo different morphological, physiological, biochemical, and rhizosphere mediated modification to enhance nutrient absorption under nutrient deficiency. Morphological changes modifying root architecture promoting lateral root, shoot branching and leaf senescence. Also associated with different bacteria and fungi to increase nutrient uptake. Rice plant may increase the expression of different nutrient transporter that help to increase acid phosphatase activity and promote organic acid secretion. Under phosphorous stress plants try to maintain cellular Pi homeostasis in cytoplasm and also increased synthesis of anthocyanin.

1. **Morphological response**

a) **Root Morphology**

Roots are the primary contact point of plant with soil. Its morphology and physiology are closely associated with the growth and development of aboveground parts. High root biomass and root oxidation activity in roots are required for achieving high panicle number, Spikelets per panicle, grain-filling percentage, and grain yield.

b) **Root Architecture**

Modifying root architecture is an important strategy to improve NUE under nutrient deficient condition, additionally root architecture adaptation mechanism including horizontal growth of basal root, Shallower growth angle of axil root, increased adventurous root, increased lateral root formation resulted in enhanced axial root length.

c) **Symbiotic interaction with rhizosphere microorganism**

Symbiotic interaction with rhizosphere microorganism most important adaptation strategies to enhance nutrient acquisition efficiency under stress condition. Arbuscular mycorrhizal fungi (AME) play a important role in enhance PAE in growing plant on P deficient soil. Under P deficient condition AME colonize plant roots to obtain energy and promotes root growth by increasing the length and number of lateral roots and root biomass.

2. **Biochemical and physiological responces**

a) **Anthocyanin accumulation**

Anthocyanin one of the major group of flavonoids act as a antioxidant under several stress condition. In rice genes are involved anthocyanin biosynthesis such as OsC1 (MYB transcription factor) and OsDFR (dihydroflavonol 4-reductase). Under P stress condition the activation of anthocyanin biosynthesis genes in response to phosphate starvation.

b) **Acid Phosphatase release under nutrient stress**

Acid Phosphatase (ACPs) secretion is one of the major adaptive responses to inorganic phosphate deficiency in the rhizosphere. Intracellular acid phosphatases recycle phosphorus within the plant by breaking down internal P-containing compounds, especially under severe deficiency. genes such as **OsPAP10a and OsPAP26**, which encode acid phosphatase in rice under P stress.

Nutrient Uptake and management Strategies in Hydroponics

Nutrient management is one of the core successes in hydroponics system precicesd balance nutrient solution to thrive plant in a soil less environment. Unlike traditional cultivation where plant extract nutrient from soil, hydroponics reliy on nutrient solution infused with macro and micronutrient.

1. **Maintaining Nutrient Concentration**

One of the fundamental principles of nutrient management in hydroponics. Maintaing proper nutrient concentration and ratio to meet the specific need of different growth stage and solution must be formulated carefully ensuring that plant have access to all nutrients for growth and development.

2. **PH adjustment**
Moreover, it is directly impacts nutrient availability and uptake by plants. For rice prefer PH range 5.5 to 6.5 which allow optimal absorption and healthy root. As result nutrient management in hydroponics system involves several factors such as water quality, temperature, and oxygenation. High-quality water free from contaminants such as chlorine, chloramines, and heavy metals is essential for preventing nutrient imbalances and maintaining plant health.

Limitation and Future prospect

Although soil-less cultivation offers numerous advantages, it also comes with certain limitations. One of the primary challenges is the requirement for technical expertise and a high initial investment, especially for commercial-scale operations within controlled environments. Maintaining optimal conditions for plant growth demands skilled management and precise monitoring. With the global population projected to reach 9.6 billion by 2050, food demand is expected to increase by up to 70%. Given that approximately 80% of arable land is already in use, conventional agricultural methods alone may not suffice to meet this growing demand. In this context, hydroponics opens a new frontier in agricultural science, enabling higher crop production with lower resource input. This method not only minimizes environmental impacts often associated with greenhouses and nurseries but also enhances yield quality. As a result, hydroponics emerges as a promising strategy to contribute positively toward feeding the world's expanding population, while also addressing resource constraints and environmental challenges.

Conclusion

To ensure food security and support the livelihoods of the rapidly growing global population, enhancing rice productivity and developing nutrient-efficient, stress-resilient rice varieties has become a critical priority. Addressing this challenge requires a multidisciplinary approach, especially as nutrient resource limitations are expected to become more severe in the future. One key strategy involves improving varietal tolerance to low-nutrient conditions by mitigating environmental stressors through controlled environments, balanced nutrient solutions, and low-input cultivation systems. Furthermore, modern molecular breeding techniques offer great potential for improving nutrient uptake and utilization efficiency. These advanced approaches pave the way for breeders to develop climate-resilient and nutrient-efficient rice varieties, ensuring sustainable production and long-term food security.

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Indigenous Hill Farming Practices in Northeast India: Traditional Knowledge and Sustainable Agriculture

Bivek Chakma[1], Salam Lamyanba Luwang[2], Ghanashyam Singh Yurembam[1]
[1]College of Agricultural Engineering and Post Harvest Technology (CAU-Imphal), Ranipool, Sikkim.
[2]Department of Agricultural Engineering and Technology (School of Engineering and Technology), Nagaland University, Kohima.

Hill farming in Northeast India (NEI) is an integral part of the region's economy and culture, shaped by its unique topography, climate, and traditional agricultural practices (Krishna, 2020). The region, comprising Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura, is dominated by hilly terrain, high rainfall, and rich biodiversity. NEI hill's farmers are represented by more than 100 indigenous tribes that have been engaged in different practices of indigenous farming; one such is shifting agriculture practicing for thousands of years (Nath et al., 2020). The region is bordering with Nepal, Bhutan, Bangladesh and Myanmar which makes the region is one of the world's biodiversity hotspots contributing 25% of India's total forest area. The pleasant moderate temperature is beneficial to agriculture, which is the principal activity of the inhabitants of the region. India's hilly regions have a very varied terrain and climate, with variations in slopes, rainfall, and vegetation that vary greatly by location.

In the North Eastern Region of India having rich organic soils, enough water and good climate are few characteristics which allow some level of underdevelopment of agriculture. This has been possible despite the absence of appropriate technologies/planning, difficult topography, established markets, transportation facilities etc. Increase in the level of agriculture in NER, certainly, will help to close the supply-demand gap that will

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likely develop in near future and would also help in raising the income of rural farmers and improving socio economic development of the region (Vaid, 2020). The agricultural economics of the NER are characterized by the majority of small and marginal farmers. A large percentage of small and marginal farmers are forced to use economically unviable production systems because they are stuck with low-input, conventional farming methods (Barah, 2007). Hills and mountains provide a wide range of ecosystem services, including apparent beauty, natural vegetation, clean and green surroundings, pure air, and attractive sceneries (Saha et al., 2024). In hilly regions, the intricate relationship between terrain and climate presents both possibilities and limitations. Despite having abundant natural resources, the NEH region's poor economic growth and development performance is cause for serious worry (Barah, 2007). Over 80% of the population in these states depends on agriculture and related industries, yet their resources are scarce, their economic standing is low, and their ability to invest is constrained.

Indigenous agricultural methods are essential for supporting sustainable farming, protecting biodiversity, and ensuring local populations' access to food, especially in areas like NEI that are both environmentally and socioeconomically sensitive. In addition to being low-input systems that support sustainability, these traditional techniques are frequently customized for particular ecological circumstances and rely on in-depth understanding of local surroundings, such as soil health, agro-climatic conditions, and native crop types. For instance, methods like shifting cultivation, agroforestry, intercropping, and seed saving help manage pests and improve soil fertility without the use of artificial pesticides, supporting many rural households and aiding in the preservation of agro-biodiversity. Additionally, these activities promote community resilience and cultural identity, particularly in the face of commercial agricultural development and climate change. Valued habitats can be preserved and sustainability improved by acknowledging and incorporating traditional knowledge into contemporary farming systems.

2. Indigenous Hill Farming Practices

a) **Shifting (Jhum) Cultivation:** A widely practiced method where farmers clear forest patches, cultivate crops for a few years, and then leave the land fallow for regeneration (Ramakrishnan, 1992). While it sustains livelihoods, concerns about soil degradation, deforestation, and declining yields have led to debates on its sustainability (Tripathi & Barik, 2003). Shifting Cultivation is also called Jhum cultivation (local name in NER) and in essence means clearing and burning of forested land for growing crops which is followed by cultivation for a couple of years. Soil recovery follows this process where soil naturally restores itself when the area is devoid of vegetation.

b) **Zabo Farming:** Zabo farming integrates animal agriculture, crop farming, forestry and water harvesting (Fig 1). Originating in Nagaland, Zabo is exemplary in its conservation-focused design, and this is also the meaning of the term "Impounding Water".

Fig 1: Zabo farming practised in Nagaland

c) **Apatani Cultivation:** This system of wet rice cultivation and fish farming in terraced fields is practiced by the Apatani tribe in Arunachal Pradesh. It is noted for the elaborate water management and nutrient cycling systems which maximize productivity while minimizing impact on the environment.

d) **Terrace Farming**: In hilly areas like NEI, where steep slopes and intense rains may cause significant soil erosion and nutrient runoff, terrace farming is a traditional agricultural method that is extensively used. To slow water flow and to mitigate erosion, the approach consists of building a series of flat, step-like platforms along the surface of the slopes. The terraces act as physical barriers, protecting soil moisture, allowing water infiltration, and reducing nutrients loss. They form an important component of soil conservation techniques in sloping terrains (Barah, 2007). Often, terraces are built with stone walls or grass bunds for soil conservation; these structures help maintain soil structure and prevent landslides. On terraced plots, farmers can also use intercropping practices, cover crops, and organic manure to maintain soil fertility. Over time, this combination of biological and mechanical methods increases agricultural output while protecting the environment (Saha et al., 2024).

3. Ecological and Cultural Significance

a) **The role of soil in maintaining fertility and halting erosion:** In addition to providing support for plants and animals and controlling water cycles, soil is an important part of human life. In addition to food security, maintaining soil fertility, halting soil erosion, and conserving soil are critical to maximizing agricultural output and ecological sustainability.

b) **Maintaining Soil Fertility:** Plants require a sufficient amount of organic matter, minerals, air and water to grow in healthy soils. The supply of nutrients needed for plants to grow is called soil fertility. The following are crucial procedures and actions taken to maintain soil fertility:

- **Organic Matter:** Adding compost, decayed plant materials, and manure to soil improves its structure and water retention.
- **Microbial Activity:** Breaking down of organic matter by beneficial bacteria and fungi yields vital nutrients such among of nitrogen and phosphorus.
- **Crop Rotation:** Growing diverse crops helps to control pest and disease outbreak thereby reducing nutrient depletion.
- **Cover Crops:** Replenishment of nutrients as well as enhancement of the soil structure is done by planting clover or legumes during the off season.

c) **Preventive Strategies for Soil Erosion:** The erosion of topsoil brought on by wind, water, or human activity causes land degradation and long-term sterility. An essential component of soil management and land use planning is erosion control. Effective actions consist of:

- **Vegetative Cover:** Plants and grasses serve as biological barriers at a site. Additionally, roots keep the soil cohesive, reducing soil erosion.
- **Contour Farming:** Ploughing along the contour of a region helps to reduce drainage which in turn prevents soil erosion.
- **Terracing:** Creating steps dramatically reduces soil erosion while increasing the capacity of water infiltration.
- **Mulching:** To do this, just cover the top soil with dried leaves, straw, or any other type of vegetation that will prevent direct rain and wind from affecting it.

d) **Water Management and Conservation Techniques:** One of the most precious of all natural resources, water is equally important to industry, human living conditions and agriculture. New approaches to water management and conservation are needed given the current problems associated with expanding demand as well as climate change effects on water supplies. In order to maintain the quality of the resource in perpetuity, these approaches seek to reduce waste and increase efficiency.

e) Effective Water Management Techniques:

- **Rainwater Harvesting**: Collecting rainwater from rooftops and storing surface runoff assists in water supply consumption, irrigation, and groundwater recharge.
- **Drip Irrigation**: This agricultural water management technique improves water use efficiency by applying water to the base of the plant to minimize evaporation.
- **Greywater Recycling**: Using water from bathtubs, sinks, and washing machines for irrigation or landscaping diminishes the burden placed on freshwater resources.
- **Watershed Management**: Active and systematic restoration of watersheds is fundamental for the efficient management of water supplies and controlling the flow of rivers and lakes.

f) Water Conservation Methods

- **Reducing Water Waste**: Adoption of steps like leak fixing, progressively adopting water-conserving technology, and practicing judicious use of water in daily activities can go a long way in reducing waste.
- **Mulching**: Mulching or applying the organic by-product of straw or wood chips surrounding plants, assists in reducing evaporation from the soil.
- **Drought-Resistant Crops**: The cultivation of these crops that require minimal water enables farmers to continue agricultural activities during dry spells.
- **Desalination**: Making seawater suitable for drinking using modern methods has the potential to supplement water in dry regions.

g) Sacred Landscapes and Spiritual Connections

Sacred and spiritual beliefs are closely linked to agricultural activities in NEI, which reflects a strong reverence for the natural world and its divine implications. This relationship is exemplified by the existence of holy groves—forested regions kept out of religious and cultural reverence—among many indigenous people, including the Khasis, Garos, Mizos, Naga tribes, etc. These groves are closely guarded by customs and taboos since they are frequently thought of as the homes of deities, ancestor spirits, or nature gods (Hazarika, 2015). These places are off-limits to farming, logging, and hunting, and their preservation is crucial for maintaining ecological balance, preserving soil, and controlling river flow—all of which are essential for sustainable agriculture. In the State of Manipur, sacred groves, also referred to as Umang Lai natively, are essential to the connection of spirituality, culture, and environment. Traditionally, the Umang Lai worship event revolves on these groves, which are devoted to the local forest deities known as Lai. Rituals, music, and dancing are all performed in honour of these deities (Kandari et al., 2014).

4. Challenges and Threats to Traditional Agricultural Practices

(a) Impact of Government Policies and Land-Use Restrictions

- **Legal and Regulatory Challenges:** Attempts to safeguard forest ecosystems and improve agricultural practice have at certain moments in the past, affected well-entrenched traditional systems negatively. In the majority of states, the shifting cultivation method is increasingly considered a forest encroachment, with legal action against such entrenched practices being taken without providing any potential alternatives.
- **Restrictions to Access Forest Land:** The restrictions on access to forest land, regulated by different conservation legal systems, have disproportionately affected indigenous people relying on such land for their rotational farming. Absence of formal titles to the land exacerbates such vulnerability.

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- **Withdrawal of Community Assets:** The interface between customary rights systems, community-based resource management, and traditional systems takes place in an integrated manner.

(b) Climate Utilization and Conservation for the Environment

- **Seasonal Water Capture:** Erratic rainfall and changing monsoon cycles have disrupted cropping calendars. Systems like Zabo, which are heavily dependent on seasonal water capture, are especially vulnerable to these changes.
- **Soil Degradation and Erosion:** Deforestation, along with slope instability, augments erosion and severely reduces soil fertility due to the lack of land reserves cultivated using the shifting method.
- **Sustainability:** Ecosystems are highly reliant on sustaining life varied wild species, but biodiversity is in stark decline. This is happening due to monoculture shifts, deforestation, and habitat splitting.
- **Water Scarcity:** Significant reduction in snow, changing weather patterns, and receding water springs are endangering water purchasing, Zabo and Apatami are heavily reliant on features snow and sustained rains to.

(c) Socio-Economic Pressures and Migration

- **Migration from rural regions:** There is an acute shortage of educated people in rural farming communities as they migrate to cities searching for better job opportunities, leading to a shift in the demographic outlook.
- **Declining Agricultural Workforce:** The remaining population that is engaged in farming, predominantly the aged, finds it difficult to cope with the work-intensive system of terraced farming or rotational cropping. This gap in labor supply also inhibits community farming which is essential in primitive systems.
- **Economic Pressures and Crop Preferences:** Some farmers have shifted from subsistence farming towards embracing a more market-oriented economy. This shift increases the prominence of cash crops, which is detrimental to food security, disrupts ecological balance achieved through polyculture, and threatens biodiversity.
- **Cultural Knowledge and Information Deprivation:** As people modernize, and younger generations become increasingly detached from traditional ways of farming, there is an observable erasure of indigenous knowledge systems pertaining to soil management, seed saving, and ecological watching.

(d) Specific Challenges in Shifting Cultivation

- **Increase in Multicropping Period:** Fallow periods were previously estimated to be 10-15 years to allow forests and soil to recuperate. Now, shifting cultivation is forced to cope with a meager 2-3 years of fallow, leading to unsustainable forms of land use.
- **Deforestation and Resource Deprivation:** The reduction of forest cover considerably decreases the availability of essential resources such as biomass for mulching and timber for construction, which in turn makes shifting agriculture increasingly unsustainable.

(e) Threats to Zabo Farming

- **Climate Vulnerability:** The Zabo farming system is highly reliant on receiving consistent rainfall. Modification in the timing and intensity of rainfall reduces the dependability of the water harvesting systems, rendering farming more precarious.
- **Institutional Neglect:** Zabo farming is ignored services extension programs and weak policy frameworks, disbursing no subsidized aid sow assistance. This lack of essential technical aid and lack adequate financial support stifles advancement.

(f) Challenges to Apatani Cultivation

- **Land Encroachment and Infrastructure Expansion:** Urbanization, road construction and other development activities are expanding external settlements over these agricultural spaces. This encroachment does not only reduce the available cultivation area but also alters the hydrologic systems important for Apatani cultivation.
- **Shifts in market demand:** There is a gradual shift towards modern consumer tastes and away from traditional foods. This change decreases the motivation to practice arduous indigenous farming techniques.

5. Moving Towards a Sustainable Future: Adaptation and Sustainable Practices

- **Integrating Traditional and Modern Knowledge:** Scholars have shown that technology can be useful alongside traditional practices. For example, remote sensing of jhum cycle monitoring would greatly improve its efficiency, as would the addition of drip irrigation to the Zabo systems
- **Policy Change and participation of the society:** Polices should not hinder traditional farming practices but rather assist and promote them. Steps like granting customary practices of dwelling places property laws and hearing local policies are very essential.
- **Strengthening Community-Based Models:** Allowing local people to control and take responsibility for their environment and sociological dynamics, not only improves the environment, but also helps the society strengthen its resilience. Community-driven conservation initiatives have played a positive role in supporting traditional lifestyle activities while enhancing opportunities.

Traditional farming practices such as shifting cultivation, Zabo farming, and Apatani agriculture are not just historical artefacts; rather, they serve as models of sustainability and ecological understanding. Nevertheless, they face a multitude of risks, such as legal structures, cultural decline, changes in socioeconomics, and alterations in climate. In response to these socioeconomic and environmental challenges, farmers using these techniques are trying to formulate new strategies by blending old techniques with modern approaches. It is amazing how traditional agricultural practices promote the improvement of cultural heritages while seamlessly transforming without detrimental effects to the environment. In regions where shifting agriculture is practiced, some people have reverted to a more traditional practice of extended fallow rotations using nitrogen fixing plants to improve and sustain the soil. Others are experimenting with agroforestry by intercropping fruit-bearing shrubs with annual crops to enhance soil health and increase nutritional diversity. These changes are also becoming visible in Zabo farming, where new water harvesting techniques and contour cultivation are being taught through community leadership workshops to ensure knowledge capture and empower the youth to transform the future with new ideas.

6. Conclusion

Throughout North-East India, hill farming has been a major source of income for local communities. While indigenous hill farming practices have been shown to be highly ecologically useful, the sustainability and economic viability of this type of agriculture can be enhanced through the use of modern technology as well as government support. A balanced approach between modern technology and the traditional knowledge of the hill regions can help to ensure long-term agricultural sustainability. Studies have shown that the application of sustainable traditional practices and modern agricultural methods may improve environmental sustainability and production.

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Crop Rotation as a Climate-Smart Practice: Maximizing Productivity and Sustainability

Sourav Basak, Sharmishtha Mandal, Anannya Dhar, Saikat Dey

Division of Agronomy, School of Agriculture and Rural Development, Ramakrishna Mission Vivekananda Educational & Research Institute, Narendrapur Campus, Kolkata, West Bengal

Crop rotation is a climate-smart agricultural practice that enhances productivity and sustainability by improving soil health, mitigating climate risks, and ensuring long-term yield stability. By diversifying crop sequences, farmers can break pest and disease cycles, reduce chemical input dependency, and enhance soil nutrient availability. This practice contributes to climate resilience by improving water retention, increasing carbon sequestration, and reducing greenhouse gas emissions. Additionally, crop rotation offers economic benefits by stabilizing yields, optimizing resource utilization, and reducing production costs. Technological advancements, including precision farming and data-driven crop selection, further enhance crop rotation. Policy support, incentives, and awareness programs play a crucial role in promoting widespread adoption. This article explores the multidimensional benefits of crop rotation, emphasizing its significance in sustainable agriculture and climate change adaptation towards the global farming community.

Introduction

The accelerating global population, coupled with shifting climatic patterns, presents formidable challenges to food security and agricultural sustainability. Ensuring a resilient and sustainable agricultural system is imperative for maintaining long-term food availability, preserving ecosystem services, and mitigating environmental degradation (FAO, 2019). However, modern agricultural practices, characterized by mono-cropping and excessive chemical input, have led to soil depletion, biodiversity loss, and increased vulnerability to climate change. Soil erosion alone accounts for an annual loss of 25 to 40 billion metric tons (MT) of topsoil, severely depleting the world's humus reserves and reducing soil fertility (Pimentel & Burgess, 2013). The FAO estimates that soil erosion-related grain losses amount to 7.6 million metric tons (MMT) annually, with projections indicating potential losses exceeding 250 MMT by 2050, exacerbating food insecurity amid a growing global population (FAO, 2015). Scientifically informed crop rotation plays a crucial role in restoring soil health, optimizing nutrient cycles, and minimizing the environmental footprint of agriculture. It enhances soil microbial activity, reduces dependency on synthetic fertilizers and pesticides, and mitigates the risks associated with pest and pathogen outbreaks, which are expected to rise with climate change (García-Orenes et al., 2013). Additionally, crop diversification within rotational systems has been shown to increase employment opportunities, with reports indicating a 10–20% rise in job creation per hectare compared to traditional mono-cropping systems. Beyond its agronomic benefits, crop rotation aligns with the principles of climate-smart agriculture by reducing greenhouse gas emissions, improving water-use efficiency, and fostering biodiversity conservation. As the world moves toward achieving the Sustainable Development Goals (SDGs) by 2030, particularly in the areas of soil health, climate adaptation, and food security, crop rotation stands out as a viable and effective strategy for sustainable agriculture. It looks at how crop diversification may improve food security and rural lives while lowering chemical reliance, preventing soil degradation, and boosting climate change resistance.

1. How Crop Rotation Works:

Different crops have varying nutrient needs and uptake abilities, making crop rotation a key strategy for optimizing nutrient cycling and enhancing soil fertility. Legumes fix atmospheric nitrogen, deep-rooted crops like maize access subsoil nutrients, and shallow-rooted crops prevent nutrient leaching. This diversity supports microbial richness, as varied root exudates foster beneficial soil microbial interactions (Kumar et al., 2020). Crop rotation also breaks pest and pathogen cycles, reducing reliance on pesticides (Johnson & Gurr, 2022). Bio-fumigant crops like mustard and radish further suppress soil-borne diseases. Including diverse crop families—such as legumes, cereals, and brassicas—improves soil structure, aeration, and long-term productivity (Mangalassery et al., 2018). Integrating legumes and cover crops reduces the need for synthetic fertilizers, lowers nitrous oxide emissions, and enhances carbon sequestration and water quality (Drinkwater et al., 2021), contributing to climate change mitigation. Crop rotation plays a pivotal role in suppressing crop-specific pests, diseases, and weeds by disrupting their reproductive and survival cycles through temporal diversification of host plants. Alternating crops with varying rooting depths and growth habits enhances soil structure by promoting aggregation and improving aeration. Additionally, the inclusion of crops with differing nutrient uptake patterns minimizes nutrient depletion and enhances nutrient retention. This practice also supports a diverse and active soil microbiome, thereby contributing to improved soil health and long-term agroecosystem resilience.

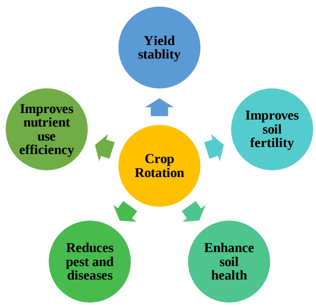

Figure 1. Benefits of crop rotation in sustainable agriculture

2.1 Climate Resilience through Crop Rotation

Climate change has intensified extreme weather events, including increased land water evaporation, leading to more frequent and severe flooding.

However, crop rotation has been identified as an effective agronomic strategy to enhance water infiltration, reduce surface water runoff, and mitigate flood risks. Baumhard et al. (2002) experimented in Texas, USA, demonstrating that retaining wheat straw residues in a rotation system improved rainwater penetration by more than 25 mm per hour in Pullman clay loam. This improvement was attributed to enhanced soil aggregate stability. Similarly, Carrol et al. (2010) found that a sunflower–wheat rotation in the Central Queensland Plateau, Australia, reduced surface runoff by 13%, increased transpiration by 17.9%, and minimized water evaporation and soil erosion when compared to continuous sunflower cropping with minimal tillage. At a broader hydrological scale, crop rotation plays a crucial role in stabilizing soil and mitigating water-related disasters. By improving soil structure and infiltration rates, crop rotation helps control flood-related factors, indirectly contributing to efficient drainage systems and watershed management (Lal et al., 2015). The practice of rotating crops increases soil organic matter, promotes root diversity, and improves water retention, which collectively reduce soil erosion and enhances resilience against extreme weather conditions.

2.2 Crop rotation on yield Stability and Economic Benefits for Farmers

Crop rotation and balanced fertilization play crucial roles in enhancing yield stability and maintaining soil fertility. Long-term studies have demonstrated that well-structured crop rotations contribute to sustainable agricultural productivity. Berzsenyi et al. (2000) highlighted that incorporating diversified crop sequences improves maize and wheat yield stability while mitigating the negative effects of monocropping. Similarly, Zhang et al. (2022) emphasized that long-term crop rotation practices in Southeast China significantly increased yield resilience by enhancing soil organic matter and nutrient availability. Ouda et al. (2018) further asserted that sustainable crop rotation practices preserve soil health, ensuring continued productivity while reducing dependence on chemical fertilizers. In regions facing climate uncertainties, Marini et al. (2020) found that rotational cropping systems contribute to yield stability, buffering against extreme weather events and climate variability. Adopting crop rotation strategies provides substantial economic benefits for farmers. One of the key advantages is the reduction in input costs associated with fertilizers and pesticides. By integrating nitrogen-fixing legumes or deep-rooted crops into rotation cycles, farmers can naturally enrich soil fertility, minimizing the need for synthetic fertilizers. This, in turn, lowers production costs while maintaining high yields. Berzsenyi et al. (2000) demonstrated that diversified rotations lead to more stable income streams for farmers by minimizing yield fluctuations. Farmers who adopt rotational farming practices also access premium markets, favoring sustainable and regenerative agricultural techniques.

2.3 Crop rotation improves nutrient use efficiency and Pest and Disease Management

Crop rotation enhances **nutrient use efficiency** in soil by diversifying plant species and their nutrient requirements. Different crops have varying nutrient demands and root structures, which helps in optimizing soil nutrient availability. For example, rotating **legumes** like **soybeans** or **peas** with cereal crops like **wheat** or **corn** can significantly improve nutrient cycling. Legumes fix nitrogen in the soil, reducing the need for synthetic fertilizers when followed by nitrogen-demanding crops like wheat. This not only improves soil health but also reduces fertilizer use, leading to cost savings and better environmental sustainability. Additionally, crop rotation helps prevent nutrient depletion, improves soil organic matter, and enhances overall soil fertility. **Shallow-rooted crops**, such as legumes (e.g., peas, beans), tend to take up nutrients from the upper soil layers. Crop rotation helps control insect pests and soil-borne pathogens by disrupting their life cycles by alternating host plants. Since many pests are host-specific, rotating crops reduces pest survival

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and reproduction, lowering the need for chemical pesticides. Similarly, diverse rotations suppress diseases by breaking pathogen cycles and enhancing soil microbial diversity (Francis & Clegg, 2020).

2.4 Crop Rotation on Soil Health Regeneration

Crop rotation significantly improves the soil's physical and biological properties. Alternating deep- and shallow-rooted crops enhances aeration and reduces compaction, while organic matter from residues and cover crops boosts soil structure and microbial diversity. Legumes like chickpeas and cowpeas fix atmospheric nitrogen through Rhizobia, reducing reliance on synthetic fertilizers and enriching soil nitrogen for subsequent crops. In degraded or saline soils, rotations involving salt-tolerant crops (e.g., barley, sorghum) and deep-rooted species (e.g., alfalfa) help leach salts and restore fertility (Qadir et al., 2007). Additionally, organic matter enhances soil aggregation, water retention, and erosion control, making crop rotation a key strategy for soil rehabilitation and sustainability.

Table 1. Case studies: Successful Crop Rotation Models Enhancing Farm Income

SL. No.	Location	Experiment	Outcome	Reference
1.	Eastern India	Crop rotation and tillage management in rice-fallow agro-ecosystem	Identified sustainable intensification options for rice-fallow systems through rotation and tillage practices	Kumar et al., 2020
2.	**Madhya Pradesh, India**	Simulation of various crop rotations (maize–wheat, maize–chickpea, soybean–wheat, soybean–chickpea) and nutrient management strategies using APSIM model.	Rotations with balanced mineral and organic nutrient applications improved yield stability and soil carbon levels, enhancing farmer livelihoods and ecosystem services.	McDermid et al., 2016
3.	Ontario, Canada	Long-term crop rotation experiment comparing monoculture soybean with rotated systems including corn-soybean and corn-soybean-wheat rotations	Rotated systems significantly improved soybean yields and soil health indicators such as microbial biomass carbon, enzyme activities, and aggregate stability	Agomoh et al., 2021
4.	Finland	Multi-year field experiment evaluating the effects of crop rotation and tillage (ploughing vs reduced tillage) on spring wheat yield and pest incidence	Crop rotation significantly increased spring wheat yield and reduced pest pressure (e.g., wireworms, Fusarium spp.) under both tillage systems, especially under reduced tillage	Jalli et al., 2021
5.	Kenya	Field trials evaluating different crop rotation sequences (including maize, beans, and cabbage) on potato yield and disease incidence in soils inoculated with *Ralstonia solanacearum*	Rotating potato with non-host crops like maize and beans significantly reduced bacterial wilt incidence and increased potato yield	Mwaniki et al., 2017

2. Innovations and Technological Advancements in Crop Rotation

Artificial intelligence (AI) and machine learning (ML) are revolutionizing crop rotation planning by analyzing vast datasets to optimize rotations based on soil health, weather patterns, and pest dynamics. AI-driven models can predict the best crop sequences to enhance yields and reduce input costs (Jones et al., 2021). For example, IBM's *Watson Decision Platform for Agriculture* integrates AI with farm data to recommend optimal crop rotation strategies (Smith & Patel, 2022). Decision-support systems (DSS) help farmers make informed crop rotation decisions by integrating data from soil sensors, climate models, and market trends. Tools like the *CropSyst* model enable scenario analysis for sustainable crop rotation planning (Tubiello et al., 2020). Additionally, digital farming platforms such as *Climate FieldView* and *FarmLogs* offer real-time insights into crop performance, guiding farmers in rotation selection (Anderson & Wang, 2021). Remote sensing and Geographic Information Systems (GIS) are playing a crucial role in assessing land suitability for crop rotation by monitoring soil moisture, vegetation indices, and land use changes. NASA's *Landsat* and ESA's *Sentinel* satellite imagery provide real-time data to optimize rotation schedules (Gao et al., 2022). Studies show that GIS-based crop rotation models have improved yield predictions and soil conservation efforts in regions practicing precision agriculture (Brown et al., 2021).

3. **Policy Support and Incentives for Crop Rotation Adoption**

Governments globally are promoting crop rotation to enhance soil health, reduce pest pressures, and ensure food security. The EU's Common Agricultural Policy (CAP) rewards crop diversification for its environmental benefits (Sutherland et al., 2020). In India, initiatives like the National Mission on Sustainable Agriculture (NMSA) and the Crop Diversification Programme (CDP) encourage farmers in Green Revolution states to shift from water-intensive paddy to alternatives like pulses and millets (Singh et al., 2021). Haryana's "Mera Pani-Meri Virasat" scheme offers ₹7,000 per acre for such shifts, conserving over 22,565 crore liters of water in its first year (Department of Agriculture and Welfare, 2020). Financial incentives also drive adoption in countries like the U.S., where the Farm Bill supports crop rotation through EQIP and CSP programs (Lass et al., 2019). China and other Asian nations have used subsidies to promote sustainable practices, while Canada's Agri-Environmental Program and Australia's Landcare initiative have improved yields, soil health, and profitability through crop rotation (Zhang et al., 2020). These examples underscore the role of well-crafted policies in advancing sustainable agriculture.

4. **Future Prospects and Challenges**

Expanding crop rotation to large-scale commercial farming requires integrating advanced technologies, optimizing land use, and ensuring economic viability. Precision agriculture and automated systems, such as GPS-guided machinery, are making large-scale crop rotation more feasible. One of the primary barriers to the widespread adoption of crop rotation is the lack of awareness among farmers, particularly in developing regions (Morris et al., 2020). High transition costs, including new equipment, soil testing, and training, discourage many farmers from shifting to rotation-based systems (Kassam et al., 2021). Additionally, policy gaps—such as insufficient financial incentives and unclear land-use regulations—hinder large-scale implementation (Singh et al., 2022). Addressing these issues requires targeted subsidies, farmer education programs, and clearer government policies. While crop rotation has proven benefits, research is still needed to optimize rotation sequences for different climates and soil types (Zhang et al., 2023). More studies on microbial soil interactions, carbon sequestration, and climate resilience in rotation systems are necessary (Brown & Williams, 2021). Future innovations could include AI-powered crop-planning tools, genetically improved rotational crops, and climate-adaptive rotation models (Anderson et al., 2022).

Conclusion

Crop rotation is a cornerstone of sustainable agriculture, delivering environmental, economic, and agronomic benefits. By alternating crops, farmers can enhance soil fertility, suppress pests and diseases, and reduce chemical input reliance—boosting both productivity and sustainability. It also improves climate resilience by enhancing soil structure, reducing erosion, and optimizing water use. Achieving widespread adoption requires coordinated efforts: farmers need training and access to digital tools; scientists must refine crop sequences and soil health strategies; and policymakers should implement supportive incentives. Agribusinesses and tech providers can aid with precision planning solutions. However, challenges such as low awareness, transition costs, and policy gaps hinder progress. Addressing these barriers demands greater investment in research, policy reforms, and knowledge-sharing. A holistic, multi-stakeholder approach can position crop rotation as a key strategy for food security and environmental conservation in the face of climate change.

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The Hidden Goldmine: The Benefits of Using Horticultural Waste in Animal Feed

Bhoirab Gogoi[1], Shourov Dutta[2], Prabhat Baruah[3], Puja Basumatary[4], Prasanna Kumar Pathak[5] and Sanjoy Borthakur[6]

[1] SMS (Horticulture), KVK, Jorhat, AAU, Teok, [2]SMS(Horticulture), KVK, Karbi Anglong, AAU, Diphu, [3]SMS(Animal Science), KVK, Jorhat, AAU, Teok, [4]SMS(Horticulture), KVK, Kokrajhar, AAU, Gossaigaon [5]Dean, College of Agriculture, AAU, Jorhat, [6]Senior Scientist and Head, KVK, Jorhat, AAU, Teok

The global population's rapid growth and the subsequent rise in food demand have led to an increase in agricultural and horticultural production. However, these industries produce an enormous amount of waste. Fruits, vegetables, flowers, and plant trimmings – materials once thought to have little economic value after harvest – are often discarded, creating environmental and logistical challenges. This waste, however, holds untapped potential and with proper processing, horticultural waste can be transformed into valuable feed for livestock. Using horticultural by-products as animal feed addresses waste management challenges while reducing feeding costs, conserving natural resources, and supporting sustainable farming practices.

The Scope of Horticultural Waste

Horticultural waste encompasses the discarded parts of plants cultivated primarily for food, medicinal, or decorative purposes. It includes fruit and vegetable peels, stems, leaves, pulp, and other by-products generated during post-harvest handling, processing, and retail. The Food and Agriculture Organization (FAO) estimates that up to 30% of global horticultural produce is lost or wasted during production, processing, distribution and marketing. Not only does this create a staggering volume of organic waste, but it also represents a significant loss of resources invested in production, such as water, fertilizers, and labor.

In addition, horticultural waste poses environmental challenges when disposed of improperly. When left to rot in landfills, this organic waste releases methane, a potent greenhouse gas that contributes to global warming. Recycling this waste into animal feed offers a sustainable alternative that can address these environmental concerns while benefiting both farmers and livestock.

Nutritional Value of Horticultural By-products

The nutritional value of horticultural waste varies depending on the plant species and the type of waste. However, many by-products are rich in essential nutrients like carbohydrates, proteins, fiber, vitamins, and minerals. Here are some common horticultural by-products and their nutrient content:

- **Fruit peels (e.g., citrus, banana, apple)**: High in fiber, antioxidants, vitamins (especially vitamin C), and minerals like potassium and magnesium.
- **Vegetable residues (e.g., carrot tops, potato skins, broccoli stems)**: Rich in vitamins, minerals, and fiber, which are beneficial for animal digestive health.
- **Leafy residues (e.g., cabbage leaves, spinach stems)**: Excellent sources of minerals like iron and calcium and are particularly nutritious for herbivorous livestock.
- **Fruit pulps and pomace (e.g., grape, apple, tomato)**: By-products of juice and wine production, fruit pulps are rich in fiber, sugars, and essential vitamins, making them an energy-dense food source for animals.

For livestock such as cattle, goats, pigs, and poultry, horticultural by-products offer a cost-effective, nutrient-dense alternative to conventional feed ingredients. Moreover, using locally sourced horticultural waste can reduce dependency on imported feed ingredients, thereby lowering feeding costs and enhancing food security.

Benefits of Horticultural Waste in Animal Feed

1. Cost Savings for Farmers

The rising costs of conventional animal feed are a major burden for livestock farmers worldwide. Feed accounts for a large portion of livestock production costs, especially in low-income countries. By incorporating horticultural waste into animal diets, farmers can reduce their dependency on commercial feeds and thus lower their operational expenses. For instance, citrus pulp, a by-product of orange juice production, is a low-cost energy source that can replace a portion of the grain in cattle feed without compromising nutritional quality. Similarly, tomato pomace, a by-product of tomato processing, can serve as a high-fiber supplement for dairy cows.

2. Improved Animal Health and Productivity

Horticultural waste is often rich in bioactive compounds, such as antioxidants, polyphenols, and dietary fiber, which are beneficial for animal health. Antioxidants and polyphenols, found abundantly in fruit and vegetable peels, help reduce oxidative stress in animals, boosting their immune systems and reducing the risk of disease. The dietary fiber found in horticultural waste, especially in leafy residues, promotes gut health and improves nutrient absorption in ruminant animals like cows and goats.

Studies have shown that animals fed with horticultural by-products exhibit enhanced productivity, such as increased milk yield in dairy cows or better growth rates in poultry. The high moisture content in certain horticultural by-products also helps keep animals hydrated, particularly in hot climates.

3. Reducing Environmental Impact

Conventional livestock feed production requires vast amounts of water, land, and energy, contributing to environmental issues such as deforestation, soil erosion, and water pollution. By substituting horticultural waste for conventional feed, farmers can reduce the environmental footprint associated with livestock production.

Furthermore, the use of horticultural waste in animal feed can help mitigate greenhouse gas

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emissions by diverting organic waste from landfills, where it would otherwise release methane during decomposition. Recycling horticultural by-products aligns with the principles of a circular economy, where waste is repurposed, thereby reducing environmental harm and promoting sustainable agricultural practices.

4. Diversification of Animal Diets

A varied diet is beneficial for animals, as it promotes better health, improves feed intake, and enhances nutrient utilization. Adding horticultural by-products to animal feed introduces a wider array of nutrients that may be lacking in conventional feed. For example, citrus peels and grape pomace add fiber, while fruit and vegetable residues provide vitamins that are not always present in traditional grain-based feeds.

Horticultural waste also brings unique flavors and textures to animal feed, encouraging higher feed intake among animals and potentially leading to better growth and productivity. For instance, studies show that dairy cows prefer feeds that contain a variety of textures, which can stimulate their appetite and improve milk production.

5. Local Economic Opportunities

The use of horticultural by-products in animal feed creates local economic opportunities, particularly for small-scale farmers and food processors. Small and medium enterprises can capitalize on the abundance of horticultural waste by developing feed products that cater to local livestock producers. This not only generates income but also strengthens the local agricultural economy and reduces dependency on imported feed ingredients.

By establishing networks between farmers, food processors, and livestock producers, communities can create an integrated system where horticultural waste is collected, processed, and distributed as animal feed. Such initiatives can also lead to job creation in rural areas, as they involve labor-intensive processes like collection, drying, and packaging of horticultural waste.

Challenges and Considerations

Despite the numerous benefits, there are challenges to using horticultural waste as animal feed. Some of these include:

1. Seasonal Availability

Horticultural waste is often seasonal, as it is generated during specific harvesting or processing periods. This limits the continuous supply of certain by-products and may require farmers to store or preserve the waste for future use. Preservation techniques like drying, ensiling, or dehydrating can help extend the shelf life of horticultural waste, although these methods may add extra processing costs.

2. Nutritional Variation

The nutritional composition of horticultural by-products can vary widely depending on factors such as plant species, growing conditions, and processing methods. It is essential to assess the nutritional quality of horticultural waste before incorporating it into animal diets to ensure that animals receive a balanced diet. Nutrient analysis and proper formulation of feed can help prevent deficiencies or excesses that could harm animal health.

3. Risk of Contamination

Improper handling, storage, or processing of horticultural waste can lead to contamination with harmful microorganisms, pesticides, or other chemicals. To ensure the safety of animal feed, horticultural by-products should be thoroughly cleaned, dried, and inspected for contaminants before use. Some types of waste, such as certain fruit peels, may contain natural compounds that could be toxic to animals, so these should be used with caution.

4. Processing and Logistics

Collecting and processing horticultural waste on a large scale can be challenging, especially in regions with limited infrastructure. Transporting bulky waste materials can be costly and requires logistical planning. Processing methods, such as drying or pelletizing, can help reduce transportation costs by reducing the volume of waste. However,

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establishing efficient processing facilities requires investment and coordination among stakeholders.

Processing Techniques of Horticultural Waste

Incorporating Horticultural waste in animal feed often requires processing to ensure quality, palatability, and nutritional availability. The main techniques used include drying, ensiling, and fermentation:

- **Drying**: Sun-drying or industrial drying is commonly used to reduce moisture content, enhancing storage stability and ease of transportation. For example, citrus and grape pomace are often dried to create a concentrated feed supplement.
- **Ensiling**: Ensiling is a forage preservation method based on a spontaneous lactic acid fermentation under anaerobic conditions. The epiphytic lactic acid bacteria (LAB) ferment the water-soluble carbohydrates (WSC) in the crop to lactic acid, and to a lesser extent to acetic acid. It is similar to silage, horticultural waste can be preserved through ensiling, which maintains nutrient quality and enables long-term storage. This method is particularly useful in regions with seasonal waste production.
- **Fermentation**: Fermentation enhances the digestibility of fiber-rich waste by breaking down complex carbohydrates, making it more suitable for monogastric animals like pigs and poultry.

With these methods, horticultural waste can be made into high-quality feed the nutritional needs of different livestock. Processing also helps eliminate potential toxins and pathogens, making the waste safe for animal consumption.

Practical Applications and Success Stories

Several countries have successfully integrated horticultural waste into animal feed systems, providing valuable lessons for other regions. Here are a few examples:

- **Europe**: The wine industry in Europe generates large quantities of grape pomace, which is dried and used as cattle feed. Grape pomace is rich in fiber and antioxidants, benefiting dairy cows and reducing feeding costs for farmers. Research in Spain and Italy has demonstrated that grape pomace supplementation improves milk quality by enhancing fatty acid profiles.
- **India**: India is a major producer of fruits and vegetables, generating substantial amounts of waste. Mango peels, banana stems, and pineapple residue are commonly used in livestock feed, especially for cattle and goats. These by-products are affordable, easily accessible, and rich in nutrients, making them ideal supplements for small-scale farmers.
- **United States**: The U.S. citrus industry produces vast amounts of citrus pulp and peels, which are widely used as a feed ingredient for cattle. Citrus by-products are processed into pellets, which extend their shelf life and make transportation easier. Studies have shown that citrus pulp improves feed intake, milk yield, and animal health due to its high energy content and antioxidant properties.

The Future of Horticultural Waste in Animal Feed

The use of horticultural waste in animal feed holds great promise for sustainable agriculture, but it requires collaboration among farmers, researchers, and policymakers. Innovations in waste collection, processing, and nutrient assessment can help improve the efficiency and safety of horticultural waste as feed. Some areas of future research and development include:

- **Developing new processing techniques**: Advanced drying, ensiling, and pelletizing methods can make horticultural waste more convenient to store, transport, and incorporate into animal feed.
- **Optimizing feed formulations**: Research into the nutritional composition of different by-products can help formulate balanced diets that maximize the benefits of horticultural waste while minimizing potential risks.

- **Creating incentives for farmers**: Government policies and subsidies can encourage farmers to use horticultural waste in animal feed, making this practice more economically viable and sustainable.

Conclusion

Transforming horticultural waste into animal feed presents an exciting opportunity to address several pressing global issues, from food waste and rising feed costs to environmental degradation. This practice is both environmentally sustainable and economically beneficial, allowing farmers to cut costs, enhance animal health, and reduce the impact of agricultural waste. Although challenges remain, innovations in processing, logistics, and policy support could pave the way for wider adoption of horticultural waste in animal feed. By recognizing the value of these by-products, farmers, industry stakeholders, and policymakers can turn horticultural waste from a burden into a valuable resource that contributes to a more sustainable and resilient agricultural system.

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Effect of mulching on soil physico-chemical and biological properties

Pratishruti Behera
Phd scholor, Dept of Agronomy, College of agriculture, Assam agricultural University, Jorhat

The word 'mulch' derived from the German word "molsch" means soft to decay. "Any material applied on soil surface to control weeds, conserve soil moisture (reducing evaporation) and to regulate soil temperature in favor of crop production.

Mulching is an essential practice in agricultural production. It is an application of any plant residues or other materials for covering top soil surface for conserving soil moisture, reducing the runoff and thereby to control soil erosion, checking weed growth, improving soil temperature, modifying the micro environment of soil to meet the needs of seeds for their good germination and better growth of seedlings. The main purposes for applying mulch include conservation of soil moisture, improving fertility and health of the soil, reducing weed growth. These materials are placed on a soil surface for the reducing the evaporation and retaining moisture. They also act as a barrier for movement of moisture out of the soil. They reduce soil erosion by acting as a shield for soil surface from the impact of raindrops and preventing soil crust formation, it also provides the plant nutrients as the material decomposes. Implementation of mulch increases infiltration of runoff or irrigation water and minimizes evaporation losses. They also help to improve water use efficiency of the crop.

A mulch is usually, not purely organic in nature. It may be plastic film or crop and weed biomass. Mulching is a process used both in commercial crop production and in gardening, and when applied correctly, can improve soil productivity. Utilization of eco-friendly, biodegradable mulch layer replace common plastic

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thin layer by increasing crop yield, they help in reducing agricultural water consumption, and effectively resolve the issues related to residual film pollution.

Advantages of mulch:

a. Conserves soil moisture
b. Reduces infiltration rate
c. Reduces the weed growth and keep the crop clean
d. Helps in Pest control
e. Maintains soil temperature
f. Enhances Plant growth and development
g. Improves quality and yield
h. Promotes earlier harvest
i. Reduces fertilizer leaching

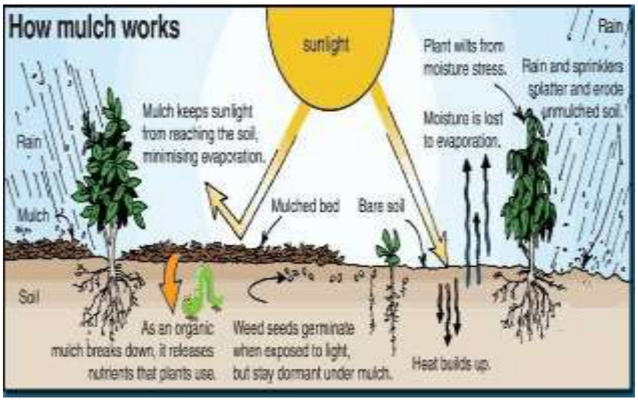

Fig:1 How mulching works

Types of mulches:-

1. Organic mulch
2. In-organic mulch

Organic mulch: Organic mulches are those that break down over time and, therefore, gradually improve the condition over time, releasing nutrients into the soil as they biodegrade. Organic mulches are generally lower cost than inorganic mulches, but because they disappear into the soil over time, they will need to be replaced periodically, which could represent a higher cost in the long run. Many types of organic mulch can be sourced for free, from leftover garden waste

a. Bark:- These are good mulch materials because they contain more moisture and retains this moisture for longer periods and helps in the supply of moisture to the growing crop. It is commonly used for vegetation and landscaping, it should be avoided to use in vegetable fields because it is acidic.

However, these mulches are excellent for cover the paths between beds.there are two types of bark mulch namely hardwood and softwood

b. Bark (Hardwood):- Hardwood bark mulches are one of the common mulches used in countryside plantings. It is a byproduct of the paper and wood industries which can be recycled as a mulch. Hardwood bark contains more nutrients than softwood bark, but they are not available easily. The pH of these types of barks is slightly alkaline.

c. Bark (Softwood): Softwood barks are tough to decay than hardwood barks. Its pH is acidic in its reaction. These barks are available in various sizes which fits in many countryside needs. Apply to a depth of 2-4 inches.

d. Grass Clipping :- Grass clipping is one of the most easily and abundantly available mulching material in Indian agriculture. If fresh grass clippings are used in the field, it decomposes easily and increases the percentage of nitrogen in the soil. The different types of grass clipping are widely available such as green or fresh and dry grass. Normally, green grass clippings are not used in the rainy season because it may chance to the development of its own root systems which will be harmful to crop growth. Apply of green clippings can heat up quite a bit and possibly cause damage to plants. So, always the dried grass always preferred to use as mulch. Apply to a depth of 2-3 inches.

e. Dry Leaves :- Leaves are beneficial for soil it contributes nutrients when used as mulch. It is widely used in natural forest areas and where trees are plentiful. Dry leaves are the easily and abundantly available and it makes a better mulch if it composted. However, dry leaves are not easily available in the spring season, they are valued as overwinter mulch. To restricts the blowing of dry leaves, small branches and wood barks are kept over the dry leaves mulch. The thickness of the dry leaves mulching is about 3-4 inches.

f. **Straw**:- Straw is ideal for mulching because it is easily applying infield, stays in place and reflects sunlight which helps to bear fruit in some vegetables. It is used as winter protection and as a summer mulch in vegetable fields. These mulches provide great insulation, water penetration and weed control. The main advantageous property is that it does not contain weed seeds itself. Straw mulches are avoided to use in high traffic areas due to its highly inflammable properties. The thickness of the straw mulching is about 6 8 inches

g. C**ompost/Manure** The compost is good mulch and soil conditioner it can easily prepare or formed at home by composting of different types of waste materials like leaves, straw, grass and plant residues, etc. The availability and application of compost in Indian agriculture is old age practice. It improves the soil properties like physical, chemical and biological properties and enhances the carbon content which improves the water retention capacity of the soil. Compost is the good material for improving the soil health. It should not be used in the vegetable field because they have too much nitrogen and it may contain weed seeds. The excellent use of compost is at the time of bed preparation or as 'top dressing' thinly in the early part of the season. It used as a mulch in some nutrient loving plants like roses. Apply at a depth of 3-4 inches.

h. **Sawdust** Sawdust is a very common type of mulch in areas where easily available. It is found during the finishing operations of wood, it has less nutritive values and it has only half of nutrients than straw. Due to high C: N ratio, the decomposition is very late**.** Its decay will cause deficiency of nitrogen in the soil, so regular fertilizer application is necessary. Its nature is acidic, so it should not be used in acidic type of soils. However, it retains moisture for longer periods.

i. **Newspaper**:- Newspaper mulching helps to control weeds and is readily available. The newspaper layer biodegrades into the soil in a small time. The newspaper is better than plastic because it will eventually decompose. Newspaper mulch can save a lot of time and effort, in fields where weeds are already matured in the previous season and dropped seeds will be germinate in the coming season. However, the usage of newspaper mulches is avoided in high windy areas. The combined sheets of 2 or more sheets of newspaper should be used and its edges should be pasted with heavy materials to safety from blowing like pebbles, gravels, etc. Commonly, use of glossy paper in vegetable fields should be avoided because the ink could leach into the soil.

j. **Alfalfa**:- It is an excellent type mulching material because it is generally cut before it can put out seeds. As a mulch, it is very nutritive for soil because it contains high nitrogen and it has also long-lasting ability.

k. **Seaweed**:- Seaweed makes an excellent mulch if it freshly collected and it contributes mineral into the soil. Seaweed shrinks a lot as if it dries, so, thick layer should be applying in field. Before applying in field seaweeds should be sprayed by fresh water to minimize the brings of salt in the soil.

l. **Cocoa Bean Hulls** :-It is an excellent mulching material to increase the soil fertility. It contains nitrogen, phosphate and potash. It is acidic in nature, pH 5.8. It is used in the landscape due to its sweet smell and attractive appearance.

m. **Corncobs (crushed)**:- It is another exceptional and cheap mulch material. Corncob mulch can be coloured for increasing its appearance and used for landscape.

n. **Hops spent:-** This mulching material obtained inexpensively and collect from local breweries. They have good appearance and they do not burn readily. It has strong odour but after half or over the year it should be used.

o. **Mushroom Compost**:- It is an organic plant fertilizer available in areas where it should be grown commercially. It is available in market as a spent mushroom compost/ spent mushroom substrate It is reasonably inexpensive. It increases the fertility of soil due to its rich nutrient values. This type of compost increases the water retention capacity of soil.

p. **Peanut hulls**:-It is a good appearance mulch that located near peanut processing areas. These are the organic mulches which are generally used in fields as a mulching material. Also, farmers using the other many crop residues available in the field as a mulch.

In-organic mulch:- Inorganic mulches are generally used to create barriers to weeds. They are also used for decorative purposes. Inorganic mulch, such as rocks or gravel, does not readily decompose. Rocks absorb and reflect heat which can be detrimental during hot, dry weather. Because they do not decompose quickly, inorganic mulches do not improve soil quality.

a. **Plastic film**:- Plastic film is impermeable – water and nutrients cannot pass through. Plastic is best used along rows of vegetables to warm the soil in spring. It is not the best choice for long-term use. Plastic film deteriorates with exposure to sunlight and is usually used for only one season.
b. **Landscape fabric: -** Landscape fabric is a better choice for long-term use to suppress weeds because it allows air and water to pass through. It can be used in conjunction with organic mulches and will decompose more quickly than most other inorganic mulches.
c. **Stone: -** Examples include volcanic rock, crushed gravel, and marble chips. Stones do not retain moisture and can cause heat stress on plants through reflection and ground heating which can burn roots. They are best used away from trees, shrubs, and other plants.
d. **Rubber mulch: -** These are composed of recycled or ground tires. This product continues to be researched; however, initial studies indicate possible toxicity levels as well as the risk of flammability. In addition, rubber mulch can remain in the soil indefinitely. It is not recommended for use in the home landscape.

Effect of mulching on soil physical properties

- Mulch helps to retain stable moisture levels by lowering water evaporation from the soil's surface.
- Temperature Regulation: By acting as an insulating layer, it keeps the soil warmer in the winter and cooler in the summer.
- Erosion Control: By lessening the effect of runoff and rainfall, mulch shields the soil from erosion caused by wind and water.
- Better Soil Structure: As organic mulches break down, they improve the porosity, aggregation, and general structure of the soil.
- Decreased Compaction: Mulch reduces compaction brought on by mechanical or foot traffic by cushioning the soil's surface.
- Improved Infiltration: Mulching improves water distribution by lowering surface runoff and increasing water infiltration rates.

Effect of mulching in soil chemical properties

Addition of Organic Matter: As organic mulches like wood chips or straw break down over time, the soil's organic matter content rises. This enhances the soil's ability to retain nutrients and fertility.

Nutrient Cycling: As mulch decomposes, vital nutrients such as potassium, phosphorus, and nitrogen are released, improving the soil.

pH Stabilization: By neutralizing the pH of the soil, mulching helps to keep the growing environment more stable. Pine needles and other organic mulches have the ability to gently lower the pH of the soil, which is advantageous for plants that like acidic soil.

Decreased Nutrient Leaching: Mulching keeps essential nutrients in the root zone by reducing water runoff, which in turn minimizes nutrient loss from the soil.

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Decomposed organic matter improves the soil's Cation Exchange Capacity (CEC), which makes it better able to hold and exchange nutrients.

Reduced Soil Salinity: Mulching slows down the rate of evaporation, which keeps salts from building up on the soil's surface and improves plant growth.

Effect of mulching in soil biological properties

- Microbial Activity: As organic mulches break down, they provide soil microorganisms something to eat, which increases microbial diversity and activity. These microorganisms are essential for enhancing soil fertility and nutrient cycling.
- Earthworm Population: By preserving moisture and supplying organic matter, mulching fosters an environment that is conducive to earthworm growth. Earthworms help mix nutrients and aerate the soil.
- Enhanced Biodiversity: By fostering the growth of several beneficial creatures, such as bacteria, fungus, and arthropods, mulching helps to create a balanced ecosystem in the soil.
- Suppression of Harmful Pathogens: Plant illnesses can be decreased by outcompeting and suppressing soil-borne pathogens with a healthy microbial community that mulching cultivates.
- Decomposition and the Formation of Humus: As mulch breaks down, humus—a stable organic component that enhances soil structure and nutrient retention—is created.
- Increased Enzymatic Activities: Mulch promotes the synthesis of soil enzymes, which are essential for the breakdown of organic matter and the availability of nutrients.

Limitation

1. Mulch can be expensive in terms of labor, transport, setting removal, and disposal.
2. The plastic film has intimate contact with soil which creates fragment and contaminants to soil (Steinmetz *et al.* 2016)
3. Organic mulching such as grass and straw contain seeds that may allow to grow weeds and release acid to soil (Chalker-Scott 2007; Patil Shirish *et al.* 2013)
4. Soils are heavily contaminated with the films which are disposed by farmers through on-site landfilling and burning (Gonzalez-dugo *et al.* 2014).
5. The plastic film fragments are discarded and buried in the arable layer which retards crop growth.
6. Many of organic mulches cause the breeding spots for many insects and pests.
7. Mulches such as hay and straw contain seeds which may become weeds.
8. These organic mulches are easily biodegradable, and they can serve for the only short period.
9. They can keep the soil too moist on poorly drained soils and restricting oxygen in the root zone.
10. The trapped moisture creates an environment conductive to the growth of diseases and pests.

Conclusion:-

a. Mulches are promising for water conservation and weed management.

b. Have immense role in rainfed farming, conservation agriculture and protected.

c. Allelopatheic effects of mulches (stover) and their nutrient recycling needs in detail understanding and further investigation.

b. Except dust mulching, others are naive to farmers. Hence needs proper extension and policy support for their exploration in India.

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Happy Seeder and Super Seeder: Technological Innovations for Sustainable Crop Residue Management

[a]Nitin Kumar Koumary, [b]Anoop Kumar Dave, [b]Viren Manish Victor, [b]Rajesh Kumar Naik, [a]Sanjay Kumar Gilhare

[a]Ph.D. Scholar, [b]Professor- Department of Farm Machinery and Power Engineering, Indira Gandhi Krishi Vishwavidyalaya, Raipur (Chhattisgarh),

Introduction

In general, Traditional paddy harvesting methods typically require 150 to 200 man-hours per hectare, making them economically unviable for most farmers (Lohan et al., 2018). Consequently, the majority of farmers now rely on combine harvesters, which streamline the harvesting process but leave behind significant crop residues approximately 20–30 cm in height or about 9 tons per hectare (Dutta et al., 2022). As farmers aim to sow wheat within 10–15 days following the rice harvest, managing this large volume of residue becomes critical. Due to time constraints, many resort to stubble burning, a practice that results in air pollution and the depletion of valuable soil nutrients (Parihar et al., 2018).

Paddy straw is known to contain essential nutrients, including 0.7 % nitrogen, 0.23 % phosphorus, and 1.75 % potassium (Goswami et al., 2020). However, burning this residue leads to the loss of these nutrients and emits a substantial quantity of harmful gases. The combustion of one ton of paddy straw releases approximately 1,515 kg of carbon dioxide (CO_2), 92 kg of carbon monoxide (CO), 3.83 kg of nitrogen oxides (NO_x), 0.4 kg of sulfur dioxide (SO_2), 2.7 kg of methane (CH_4), and 15.7 kg of non-methane volatile organic compounds (Singh et al., 2017). Such emissions contribute to serious environmental pollution, adversely affecting both human and animal health, and intensifying greenhouse gas accumulation. In addition, straw burning depletes

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soil organic matter and diminishes soil fertility (Verma et al., 2023).

To mitigate these adverse effects, several residue management strategies have been developed. Among the most effective technologies are the Super Seeder and Happy Seeder, which facilitate direct seeding into fields with standing crop stubble. These implements provide a sustainable and efficient approach to crop residue management while aligning with the evolving needs of modern agriculture.

Super Seeder and Happy Seeder

The Super Seeder is used to sow wheat in fields with standing stubble after paddy harvesting. It eliminates the need for separate machines for residue management, tillage, and sowing. All these tasks can be done simultaneously with this machine. The Super Seeder is a combination of a rotavator and a zero-till drill, which helps manage paddy residues and sow wheat in one operation.

Fig.1. Super Seeder

The Happy Seeder is a tractor-operated implement designed to sow wheat directly into paddy fields with standing rice stubble without the need for pre-tillage or residue burning. Originally developed by the Punjab Agricultural University in collaboration with the Australian Centre for International Agricultural Research (ACIAR), the Happy Seeder combines a straw management system with a seed-cum-fertilizer drill. This technology is particularly relevant in the Indo-Gangetic Plains, where burning of rice stubble contributes significantly to air pollution and loss of soil fertility (Sidhu et al., 2007).

Fig.2. Happy Seeder

Most farmers burn the remaining paddy stubble during wheat sowing, which reduces soil fertility and releases harmful gases into the environment. The Super Seeder and happy seeder, being an eco-friendly device, also helps conserve soil moisture.

Main Components of the Super Seeder and happy seeder

1. Seed and fertilizer box
2. Rotor axle
3. Rotor blades
4. Seed and fertilizer metering system
5. Universal shaft
6. Ground wheel
7. Furrow opener
8. Press wheel (Happy Seeder does not include press wheels)

Working Principle of the Super Seeder and Happy Seeder

The Super Seeder requires a tractor of at least 45–60 HP. It is attached to the tractor via a three-point linkage system. The universal shaft connects the PTO (Power Take-Off) of the tractor to the Super Seeder, which drives the rotavator. The seed and fertilizer metering system determines the required quantities of seed and fertilizer for sowing. The ground wheel rotates the shafts, which helps drop the appropriate quantity of seed and fertilizer into the furrows opened by the furrow opener, and the press wheel covers them with soil.

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The Happy Seeder functions by utilizing a straw management rotor to cut and lift standing stubble while simultaneously placing wheat seeds into the soil using zero-till tines. The residue is then spread as mulch over the seedbed, which aids in conserving soil moisture, suppressing weed growth, and improving organic matter content. This dual-action process allows sowing and mulching in a single pass, reducing fuel, labor, and time requirements. It operates efficiently with 45–50 HP tractors and is suited for smallholder fields.

Difference Between Happy Seeder and Super Seeder

Feature / Aspect	**Happy Seeder**	**Super Seeder**
Primary Purpose	Sowing wheat directly into paddy fields with standing stubble	Simultaneous paddy residue management and wheat sowing
Residue Management	Retains stubble as surface mulch	Chops and incorporates residue into the soil (acts as organic manure)
Component Combination	Straw management rotor + seed-cum-fertilizer drill	Rotavator + seed-cum-fertilizer drill
Press Wheel	Not available	Equipped with press wheels for seed covering and soil contact
Residue Handling	Leaves chopped residue on surface	Mixes chopped residue into the soil
Soil Disturbance	Minimal (conservation tillage)	Moderate (rotavation involved)
Fuel Consumption	Lower	Slightly higher due to tillage operation
Soil Moisture Conservation	High, due to surface mulch	Moderate, depending on tillage intensity
Environmental Benefit	Prevents burning; supports conservation agriculture	Prevents burning; enriches soil with incorporated residue
Tractor Power Requirement	~45–50 HP	~45–60 HP
Best Use Case	Conservation agriculture and surface mulching	In-situ residue incorporation and seedbed preparation
Cost	Generally lower	Slightly higher due to rotavator component

Advantages of the Super Seeder and happy seeder

1. Effectively chops and incorporates crop residues into the soil, transforming them into valuable organic manure.
2. Facilitates direct sowing of wheat without the need to burn paddy stubble.
3. Ensures precise seed placement at optimal depth and spacing, promoting uniform germination and improved crop establishment.
4. Completes field preparation in a single operation, thereby reducing per-hectare production costs for wheat.
5. Equipped with an efficient metering system that minimizes seed wastage.
6. Contributes to enhanced crop productivity and overall grain quality.
7. Environmentally sustainable solution that also helps in conserving soil moisture

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Conclusion

The sustainable use of natural resources, without causing harm to the environment, is vital for long-term agricultural productivity. The Super Seeder and Happy Seeder offer effective and practical solutions for crop residue management, eliminating the need for residue burning. These technologies simplify field operations for farmers by enabling timely wheat sowing while preserving soil health. Additionally, they provide a cost-efficient approach that conserves energy and reduces labor, all while maintaining essential soil nutrients.

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Biochar as a Carbon Farming Tool: Potential, Challenges, and Future Perspectives

Arindam Mandal, Joydeep Singha Roy, Babita Seni
M.Sc. Scholar, Department of Agronomy, School of Agriculture and Allied Sciences,
The Neotia University, Sarisha, Diamond Harbour, South 24 Parganas, West Bengal

Biochar, a carbon-rich substance produced through the pyrolysis of organic matter, has gained attention as a potential tool for carbon farming and climate change mitigation. This review aims to provide a comprehensive analysis of biochar's role in carbon farming, focusing on its mechanisms of carbon sequestration, effects on soil health, and greenhouse gas emission reduction. The physical and chemical properties of biochar, which are influenced by pyrolysis conditions and feedstock type, are crucial in determining its performance in soil restoration applications. Despite the benefits of biochar, challenges and limitations need to be addressed, including variability in biochar properties, knowledge gaps, economic considerations, and environmental concerns. Future perspectives and research directions are discussed, highlighting the need for standardization, economic incentives, and sustainable practices to overcome existing challenges and harness the full potential of biochar in carbon farming and sustainable agriculture.

Introduction

The pyrolysis process, which involves heating organic matter in a low oxygen atmosphere, produces biochar, a substance rich in carbon. Biomass, including organic municipal trash, forestry leftovers, and agricultural waste, is converted by thermochemistry into a stable form of carbon (Xie *et al.*, 2016). The main reason biochar is a desirable soil supplement is because of its extremely porous structure, which increases the soil's surface area and capacity to retain water (Maurya & Hande, 2014).

Since Biochar does not contain many readily available nutrients, it is applied in conjunction with fertilizer (Lychuk *et al.*, 2015).Carbon dioxide from the atmosphere can be remarkably captured and stored by biochar. Bio-char efficiently and sustainably sequesters carbon in agricultural soils, reducing greenhouse gas emissions. Because of its stable carbon structure, biochar acts as a carbon sink, lowering the concentration of greenhouse gases by preventing carbon from being released back into the atmosphere (Supriya, 2023).

Depending on the desired final product qualities, the pyrolysis process is conducted at temperatures between 300°C and 700°C. Cellulose, hemicellulose, and lignin—three important components of biomass—are broken down during pyrolysis, which involves a sequence of intricate chemical reactions involving organic molecules. The physical and chemical characteristics of the resulting biochar are influenced by the pyrolysis temperature, heating rate, and residence duration, making it extremely adaptable for particular uses (Jangir *et al.*, 2017).

A farm management strategy known as "carbon farming" uses techniques to sequester atmospheric carbon in the soil as well as in crop roots, wood, and leaves. The ultimate goal is to extract CO2 from the atmosphere and permanently store it in the soil (Lampridi *et al.*, 2019). Carbon farming and climate-smart agriculture (CSA) are key strategies in the effort to mitigate climate change and promote agricultural sustainability at the same time. These tactics aim to reduce greenhouse gas emissions, improve soil health, and ensure food availability in the face of looming climate change difficulties (Bayata & Mulatu, 2024).

The review titled "Biochar as a Carbon Farming Tool: Potential, Challenges, and Future Perspectives" aims to provide a comprehensive analysis of biochar's role in carbon farming. Its primary objectives are to evaluate biochar's potential in sequestering carbon, assess its effectiveness in enhancing soil fertility and crop yields, and identify the challenges associated with its large-scale implementation.

The scope of the review encompasses an examination of current research findings, analysis of case studies where biochar has been applied in agricultural settings, and exploration of future perspectives, including policy implications and technological advancements necessary for integrating biochar into sustainable farming practices.

2. Biochar as a Carbon Farming Tool

2.1 Mechanisms of Carbon Sequestration

In order to stop carbon emissions into the atmosphere, sequestration of carbon entails capturing and storing carbon in soil. One effective strategy for reducing the effects of climate change is the storage of carbon in soil. The process of turning atmospheric carbon into biochar and applying it to soil has gained more attention recently. Biochar amendment of soil is an excellent way to slow down climate change by storing carbon, which has additional positive impacts on agriculture and the environment overall. Biochar added to the soil also lowers emissions of CH_4 and N_2O. It offers appropriate solutions for managing agricultural waste, improves soil sustainability, lowers the need for fertilizers, and has a number of other possible advantages (Bassey & Oko, 2023)

Carbon is sequestered in the soil as a result of the constant fall of branches and leaves from vegetation, which enriches soils with new organic materials. When plants die, additional biomass is added,which decomposes and produces soil organic matter (SOM). Enhancing soil health, increasing crop yields, and improving plant nutrient utilization all depend on the sequestration of organic carbon (Rahman *et al.,* 2020).

Unquestionably, the ambient temperature is rising, and reports indicate that it is doing so at a never-before-seen rate. Global surface temperatures have risen by 0.88˚c since the late eighteenth century. The three main anthropogenic greenhouse gases (GHGs) that are emitted into the atmosphere by burning fossil fuels and biomass as well as the breakdown of above- and belowground organic matter are carbon dioxide (CO_2), methane (CH_4), and nitrous oxides (NO_2) (Layek *et al.,* 2022).

2.2 Effects on soil health

Through a number of interrelated processes, biochar improves soil health and sequesters carbon, both of which are essential for repairing damaged soils and raising agricultural output. The improvement of soil physical characteristics is one of the main ways biochar promotes soil health. Its high porosity and sizable surface area provide an ideal setting for aeration and water retention. Biochar increases soil porosity, which enhances water infiltration and decreases surface runoff, increasing the amount of water accessible to plant roots. Improved water retention can significantly increase crop resilience in drought-prone areas, making this trait very advantageous (Vijaykumar, 2019).

One of the distinguishing characteristics of biochar is its porous structure, which significantly enhances the physical characteristics of soil. Its holes improve microbial activity and root growth by increasing soil aeration (Voruganti, 2023)

Understanding the scope and complete ramifications of the interactions and changes that biochar undergoes throughout time within the soil system is crucial for developing a tool that can enhance soil characteristics, processes, and functioning—or at the very least, prevent adverse effects (Verheijen *et al*., 2010).

2.3 Greenhouse Gas (GHG) Emission Reduction

Biochar can lower greenhouse gas emissions in a number of ways besides sequestering carbon. First off, biochar made from biomass produces bioenergy like syngas and bio-oil, which can take the place of energy sources derived from fossil fuels. The production of biochar lowers the emissions of greenhouse gases linked to conventional energy production, such as carbon dioxide, methane, and nitrous oxide, by replacing fossil fuels. (Supriya, 2023).

3.Biochar Properties

The pyrolysis conditions and feedstock source have a significant impact on the characteristics of biochar . When compared to manure-based biochar, wood biochar generally has a lower total ash content, a higher total C content, a lower total N, P, K, S, Ca, Mg, Al, Na, and Cu content, a lower potential cation exchange capacity (CEC), and exchangeable cations. The ash content, pH, and surface basicity all rose as the pyrolysis temperature rose, whereas the surface acidity dropped (Mukherjee & Zimmerman, 2013). Biochar and synga are the primary products of slow pyrolysis, in which the biomass is gradually heated to the required peak temperature. In fast pyrolysis, the biomass is heated quickly to 400–550°c (Berek, 2014). Higher surface area and porosity, low bulk density, higher cation exchange capacity (CEC), neutral to high pH, and higher carbon content are some of the crucial physicochemical characteristics of biochar (Major *et al*., 2010). Additionally, it has N, P, and basic cations like Ca, Mg, and K. These are necessary plant nutrients for crop development and growth. Higher temperatures produce biochar with higher C content, wide surface area, high adsorption properties, greater porosity, and more stable C, whereas low-temperature pyrolysis produces more biochar (jindo *et al*., 2014). The material has a high degree of condensation and becomes more resistant with a polycyclic aromatic structure when the functional groups are gradually lost at high pyrolysis temperatures (>600 °C) (Song & Guo, 2012). Because biochar contains a greater percentage of aromatic compounds, it is more resistant to chemical and biological breakdown and can remain stable in the soil for hundreds to thousands of years (Schulz & Glaser, 2012).

3. Challenges and Limitations

Although biochar has several advantages for environmental sustainability and soil regeneration, a number of issues and concerns need to be resolved to optimize its use. For biochar to be used responsibly and successfully in a variety of circumstances, researchers, practitioners, and policymakers must have a thorough understanding of these issues.

3.1 Variability in Biochar Properties

The unpredictability of biochar's properties, which can be influenced by variables including feedstock type, pyrolysis settings, and production techniques, is one of the main problems with it.The physical, chemical, and biological properties of various forms of biochar can influence how well they work in soil restoration applications (Vijaykumar, 2019).

3.2 Knowledge Gaps and Education

Even though biochar is becoming more popular, there are still a lot of unanswered questions about its long-term effects and optimal management techniques. It's possible that many farmers and land managers are underinformed on the advantages of biochar and how to apply it properly. In order to give useful advice on the proper use of biochar, including application rates, timing, and integration with other soil amendments, educational programs are crucial.

3.3 Economic Considerations

The widespread implementation of biochar may be hampered by its economic viability. For smallholder farmers in particular, the upfront expenses of producing, transporting, and using biochar may be substantial. The initial outlay of funds may discourage some farmers from using biochar, even though it can result in long-term cost savings through lower fertilizer use and higher crop yields. The economic feasibility of biochar might be improved and transportation expenses could be decreased by creating local manufacturing facilities that use waste biomass. Furthermore, financial incentives or subsidies from organizations and governments might motivate farmers to use biochar, increasing its accessibility to a wider audience (Spokas *et al*., 2012).

3.4 Environmental Considerations

Although biochar has been demonstrated to have positive environmental effects, its production and use may raise certain environmental issues that need to be properly addressed. For example, if the pyrolysis process is not adequately managed, it may result in hazardous emissions. To prevent adverse effects on nearby ecosystems, the feedstocks used to generate biochar should be supplied responsibly. To make sure that the advantages of biochar production and use outweigh any possible disadvantages, life cycle studies of these processes are crucial for assessing the total environmental impact. The overall sustainability of biochar applications can be improved by sustainable practices like using waste biomass and reducing emissions during production. Although biochar has significant potential for environmental sustainability and soil restoration, a number of issues and concerns need to be resolved to optimize its (Muñoz *et al*., 2016; Agegnehu *et al*., 2017; Xie *et al*., 2016; Jangir *et al*., 2017).

4. Future Perspectives and Research Directions

For almost two decades biochar has been proposed as a potential method of GHG removal and climate change mitigation(Brown *et al*., 2023).The manufacturing of biochar is becoming more scalable and efficient thanks to new technology. Even in remote locations, innovations like "continuous pyrolysis systems" and "mobile pyrolysis units" enable more flexible and efficient manufacturing(Vijaykumar,2019)The scientific community will probably develop new technologies and approaches for producing and using biochar as it gains a deeper understanding of the mechanisms and interactions within soil ecosystems. This will increase the role of biochar in tackling global issues like soil degradation, food security, and climate change.

5. Conclusion

In conclusion, biochar emerges as a multifaceted tool in carbon farming, offering significant potential for carbon sequestration and soil health enhancement. Its stable carbon structure allows for long-term storage of atmospheric CO_2, contributing to climate change mitigation. Additionally, biochar improves soil fertility, water retention, and crop yields, making it a valuable asset in sustainable agriculture.

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However, the widespread adoption of biochar faces several challenges. Variations in feedstock types and pyrolysis conditions can lead to inconsistent biochar properties, affecting its performance in different soils and climates. Economic factors, including production costs and market demand, also influence its feasibility for farmers. Moreover, while biochar is generally considered stable, its long-term behavior in various environmental conditions requires further research to fully understand its permanence and ecological impacts.

Looking ahead, addressing these challenges necessitates a multidisciplinary approach. Standardizing production methods can help ensure consistent quality and performance of biochar. Economic incentives, such as carbon credits, can make biochar production more attractive to farmers and investors. For instance, recent initiatives like Google's agreement to purchase carbon removal credits from Indian farms highlight the growing interest and investment in biochar as a carbon removal strategy.

In summary, while biochar presents promising opportunities in carbon farming, realizing its full potential requires concerted efforts in research, policy-making, and practical implementation to overcome existing challenges and harness its benefits for climate mitigation and sustainable agriculture.

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Electroculture - Untapped Potential or Just a Curiosity?

Manu Krishnan, T., A P SriVidhya, J Paul Mansingh
VIT School of Agricultural Innovations and Advanced Learning (VAIAL),
Vellore Institute of Technology, Tamil Nadu, India.

Introduction

Electroculture is a method used in agriculture that employs electricity to boost crop growth and induce resistance to pests and diseases. Various experiments have been conducted in the name of electroculture since the 19th century, yet it is still considered an uncharted territory of research in the agriculture field. Electroculture has not been conventionalized yet to use it for everyday agricultural practices followed by the common farmers of India. But its potential is very high and could help in changing the face of agriculture in India, if it is conventionalized.

Advantages of Electroculture

The applications in electroculture are vast and still an untapped area in agriculture. At present, only a few hi-tech farmers or farmers with indispensable capital are trying out electroculture in their farms along with researchers to find innovative ways to "electrify" agriculture. Some of the well-known applications of electroculture are:

- Increasing crop yield and improving plant health (less pest infestation and disease incidence)
- Nutrient ions contain a charge that can be manipulated or enhanced using a direct electricity supply to the soil.
- Reduced irrigation needs
- It helps in reducing the dependency of farmers on chemical fertilizers and pesticides, ensuring environment-friendly and sustainable farming practices
- Due to the continuous movement of micro and macro-organisms under the influence of

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electricity, the soil texture and structure are maintained, hence reducing the need for heavy machinery in the field

- In hi-tech horticulture methods like hydroponics, electroculture can unleash its true potential by enhancing plant growth, thereby increasing the yield.

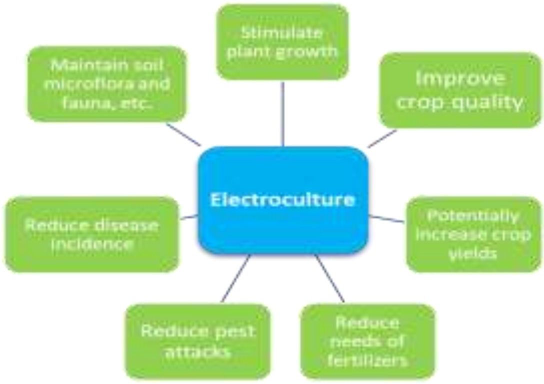

Fig 1. Advantages of Electroculture
Source: Author's Compilation (2025)

How to supply electricity to the soil?

In electroculture, electricity can be supplied to the soil or directly to the plant (in hydroponics) through many ways that follow its own unique principles. Some of the commonly used methods by researchers and farmers include:

1) **Using Electrodes**

Electrodes (rods, plates or sheets) coated with materials like copper, zinc or steel in which one of them acts as the anode (+ve) and the other one acts as the cathode (-ve) as in Fig.2. These electrodes are inserted into the soil and a circuit is formed causing the stimulation of soil particles and the organisms residing within.

Fig 2. Using copper wires as electrodes to supply electricity based on Earth's magnetism

2) **Using a power source**

The electrodes are connected to a power source of certain voltage (1-12V) that allows the invigoration of soil (Fig 3). This method of application of electricity to the soil is seldom used on small scale farms or for research purposes. The power source can be DC or AC in which both forms of power act on the soil differently and show varied effects on the crop.

Fig 3. Providing electricity to nursery plants kept in a protray using a DC source

3) **Electrolytic watering**

This method involves watering the plants with electrolyzed water containing charged ions that effectively reduces disease occurrence in the field. It is achieved by electrolyzing water with materials like zinc, copper, iron, etc. results in ionized water containing these micronutrient ions which can be easily provided to micronutrient deficient soils. This method hasn't been researched much, but it could help to achieve disease-free plants and increase yield from crops. It is most effective in hydroponics or surface irrigation methods (instead of fertigation), etc.

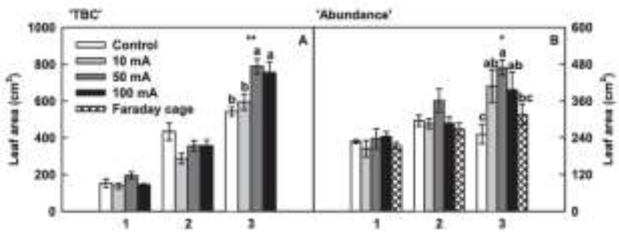

Fig. 4 Effects of Electroculture (Lee et al, 2021)

Fig. 4 shows the effect of electricity on leaf size in leaf cabbage (*Brassica oleracea*). When the soil is treated with electricity of 50 milli amperes, the plant showed up to 800cm^2 leaf area within 3 weeks of application. It is also observed that if applied excessive electricity (100 milli ampere) the leaf area could reduce or even destroy the crops. Thereby it can be said that, more electricity doesn't mean more growth. Electricity must be applied to the crop within strict borderlines and considerations (Lee et al, 2021).

Demerits of Electroculture

Thus far, the potential benefits of electroculture have been explored. However, it is important to examine the reasons why its widespread adoption has not yet occurred within contemporary agricultural practices. Since electroculture is an "under-development" practice in agriculture, the risks of practicing it are higher. Even though it is an easy method to practice with the required materials, if not used according to the proper limits, the result will be detrimental to the farmer. Some of the significant demerits of electroculture include:

- The effectiveness of electroculture is not widely accepted by the scientific community, and the underlying mechanisms are not fully understood.
- Many claims about electroculture's benefits are anecdotal or lack rigorous scientific evidence.
- The long-term effects of electroculture on plant health and the environment are not fully known.
- High cost for setting-up
- The use of electricity in agriculture raises ethical questions about the potential impact on plant well-being.

Conclusion

Electroculture could revolutionize the agriculture industry because of its effect on crops as well as on the soil. But its demerits don't allow electroculture to fulfill its buried potential. The demerits are considered 'demerits' because insufficient research has been done about electroculture. More research must be conducted on electroculture to change the status of electroculture from being a mere curiosity to a transformative practice in agriculture.

Electroculture could also be used in large-scale farming if there were robust evidence. However, there isn't much evidence to support the effectiveness of electroculture in crop production. But currently, the potential of electroculture is getting popular through social media and other community portals. This could lead to further excavation of this age-old practice and is expected to revolutionize agriculture worldwide.

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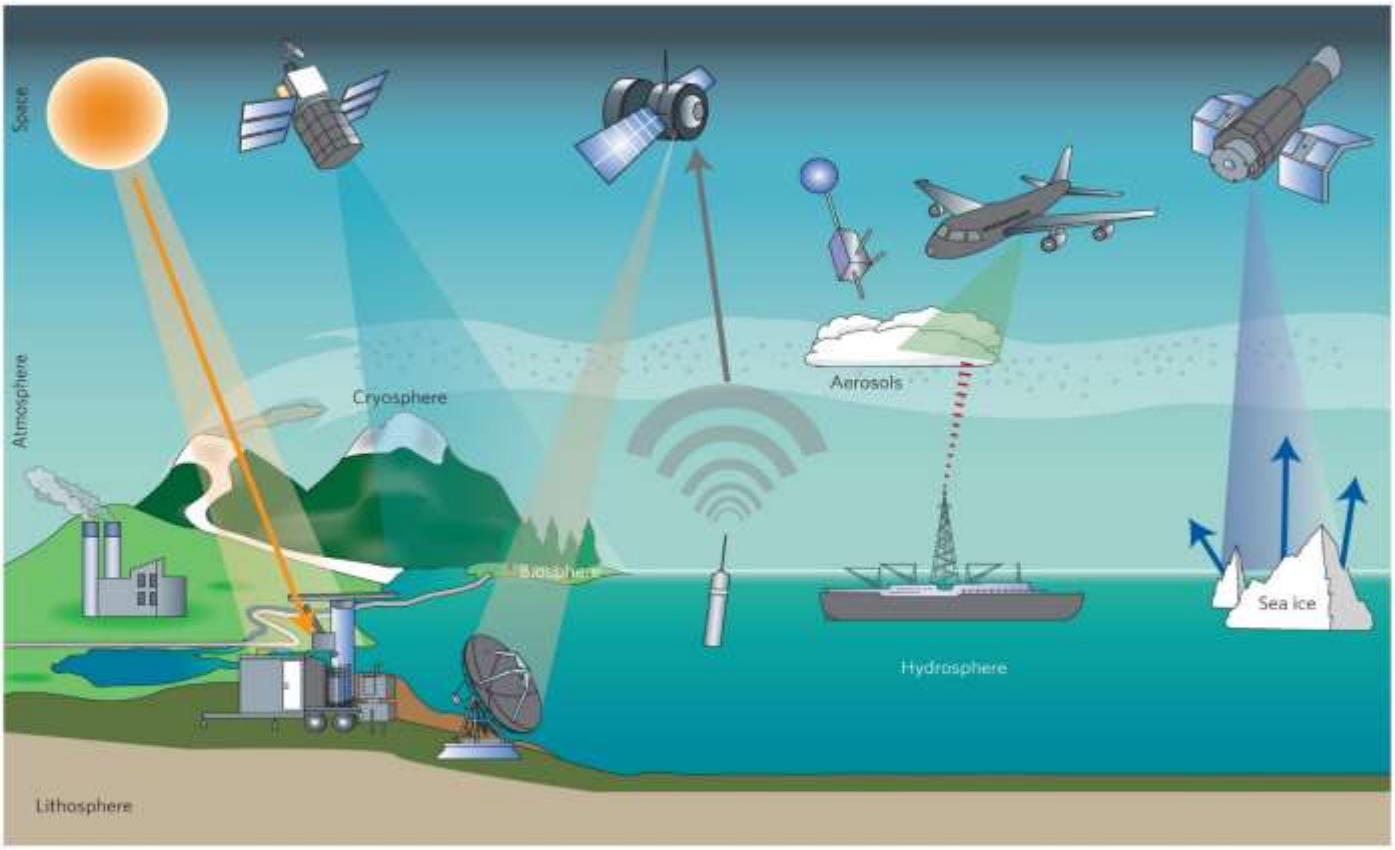

Remote Sensing and GIS in Environmental Science

Shivam Pandey[1], Devyansh Pandey[2]
[1]Project Scientist, Remote Sensing Application Centre, U.P. Lucknow
[2]M.Sc. Student, Ecology and Environment Studies, Nalanda University, Rajgir, Bihar

Geographic Information Systems (GIS) and Remote Sensing play a crucial role in environmental mapping, agriculture, mineral exploration, forestry, water, ocean, geology, disaster mitigation and management and infrastructure planning & management, etc. Remote Sensing and GIS have grown as major tools for collecting information on almost every aspect of the Earth over the last few decades.

In recent years, very high spatial and spectral resolution satellite data have been available, and the applications have multiplied for various purposes. Remote sensing and GIS have contributed significantly to developmental activities in India for the past four decades. In the present paper, we have discussed the remote sensing and GIS applications of a few environmental issues like urban environment, Mining environment, Coastal and marine environment and Wasteland environment.

The environment is something we are very familiar with in our day-to-day life. It's everything that makes up our surroundings and affects our ability to live on the earth, the air we breathe, the water that covers most of the earth's surface, the plants and animals around us, and much more. In recent years, scientists have been carefully examining the ways that people affect the environment. They have found that we are causing air pollution, deforestation, acid rain, and other problems that are dangerous both to the earth and to ourselves. These days, when you hear people talk about "the environment", they are often referring to the overall condition of our planet, or how healthy it is.

Remote sensing and Geographic Information Systems (GIS) are powerful tools for conducting environmental studies, offering insights into various aspects of the environment, from monitoring natural resources to assessing pollution and managing disasters. They enable the collection, analysis, and visualisation of spatial data, providing a comprehensive understanding of environmental issues.

Application of Remote Sensing In Environmental Studies-

Land Cover Classification and Mapping

In environmental studies, accurate and up-to-date information about land cover is critical. Remote sensing provides a high-resolution view of the Earth's surface, facilitating the classification and mapping of different land cover types. From identifying forested areas, wetlands to urban development, remote sensing technologies, such as multispectral and hyperspectral imaging, offer unparalleled data. These insights aid in urban planning, land use management, and habitat conservation initiatives.

Soil Mapping and Erosion Studies

Remote sensing plays a vital role in soil mapping and studying soil erosion. Using spectral signatures, sensors can identify different soil types, assess soil moisture levels, and detect changes due to erosion. This information is vital for agriculture, land management, and conservation planning.

Vegetation Monitoring

Remote sensing is a cornerstone in the modern approach to vegetation monitoring. Through techniques like Normalised, remote sensors can analyse vegetation cover, growth patterns, and health from space. They can also detect changes in vegetation due to factors such as drought, disease, or deforestation. This invaluable data guides decisions on resource allocation, agricultural planning, and biodiversity conservation.

Monitoring Natural Resources:

Remote sensing and Geographic Information Systems (GIS) are powerful tools for monitoring natural resources, offering a wide range of applications in areas like agriculture, water resources, forestry, and soil management. They enable the detection and tracking of changes in land cover, water quality, and other environmental factors, supporting informed decision-making and resource management.

Assessing Environmental Pollution:

Remote sensing and Geographic Information Systems (GIS) are valuable tools for assessing environmental pollution, enabling monitoring of pollutants and their distribution over large areas. By integrating remote sensing data into GIS software, researchers and policymakers can visualize pollution patterns, identify sources, and assess the impact on human health and the environment.

It helps in identifying and mapping pollution sources, including air and water contamination, by analyzing spectral signatures of pollutants.

Disaster Management:

Remote sensing and Geographic Information Systems (GIS) are vital tools in disaster management, offering real-time situational awareness, hazard mapping, and post-disaster damage assessment. They enable efficient planning, response, and recovery efforts by providing crucial spatial data and analytical capabilities.

In disaster management, the speed and accuracy of information can save lives. Remote sensing provides real-time data on natural disasters such as floods, wildfires, earthquakes, and storms. It helps in predicting, monitoring, and mitigating the impacts of these events, and aids in efficient post-disaster recovery and planning.

Climate Change Studies:

Remote sensing and Geographic Information Systems (GIS) are powerful tools for studying climate change. Remote sensing provides data on Earth's surface and atmosphere, while GIS analyzes and visualizes this data to understand spatial patterns and trends in climate-related variables. This combined approach is used for monitoring sea surface temperatures, ice cover, vegetation dynamics, and greenhouse gas concentrations, which are crucial for tracking climate trends and impacts.

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Climate change is one of the most pressing issues of our time, and remote sensing plays a vital role in understanding its impacts. Satellites monitor sea level rise, ice cap melt, atmospheric CO2 levels, and temperature trends on a global scale. This irreplaceable data contributes to predictive models and guides international policy to mitigate climate change impacts.

Environmental Impact Assessment

Remote Sensing (RS) and Geographic Information Systems (GIS) are valuable tools for Environmental Impact Assessment (EIA) due to their ability to analyse, map, and model spatial data. These technologies facilitate the identification, prediction, and assessment of environmental impacts associated with development projects or natural events, aiding in informed decision-making.

Remote sensing aids in the critical task of **Environmental Impact Assessment (EIA)**. By monitoring changes in land cover, water quality, and vegetation health before and after industrial projects, remote sensing provides objective, reliable data on the environmental impacts of human activities. This information can guide sustainable development practices and policies.

Water Resources Management

Remote sensing enables the monitoring and management of water resources, including lakes, rivers, reservoirs, and coastal areas. By analysing satellite imagery, researchers can assess water quality, detect pollution sources, and monitor changes in water levels, and support effective water resource planning and management

Air Quality Monitoring

Air pollution is a grave environmental and public health issue. Remote sensing satellites, like NASA's Aura, monitor air quality by measuring concentrations of pollutants like aerosols, carbon monoxide, and ozone. This data informs air quality forecasts, guides policy-making, and aids research on the health effects of air pollution.

Coastal Zone Monitoring

Coastal zones are dynamic and vulnerable environments. Remote sensing allows for continuous monitoring of these areas, providing data on parameters like sea surface temperature, ocean color, and coastal landform changes. This information aids in managing fisheries, protecting marine habitats, and planning coastal defences.

Archaeological Studies

Remote sensing techniques such as **LiDAR (Light Detection and Ranging)** have revolutionized archaeological studies. By using airborne or satellite-based sensors, researchers can identify buried archaeological features, map ancient landscapes, and uncover hidden archaeological sites that may be difficult to detect on the ground.

Biodiversity Assessment and Conservation

Biodiversity conservation is another key area where remote sensing has immense utility. By providing detailed data on habitats, species distributions, and ecosystem health, remote sensing can help identify areas of high biodiversity, detect threats, and monitor the effectiveness of conservation strategies.

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