AGRICULTURE 2.0

Innovations in the Modern Farming

Editors:

Dr. D. P. S. Badwal
Dr. Sushila Hooda

JUST AGRICULTURE PUBLICATIONS

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Preface

Agriculture has long served as the foundation of human civilization, adapting through time to meet the demands of evolving technologies, shifting climates and changing societal needs. Today, the agricultural sector faces unprecedented challenges, including climate change, food insecurity, resource scarcity and environmental degradation. These pressures place agriculture at a critical crossroads, where it must innovate, adapt and re-envision itself to ensure a resilient, sustainable and productive future.

This book, "*Agriculture 2.0: Innovations in Modern Farming"*, presents a curated collection of cutting-edge research and insights that illuminate the transformative innovations reshaping agriculture in the 21st century. It brings together contributions from researchers, practitioners and experts across India, united by a shared commitment to revolutionizing agriculture through sustainable practices, scientific advancements, and digital integration.

The chapters in this volume explore a wide range of topics, reflecting the complex and multifaceted nature of modern agriculture. From leveraging agricultural waste and applying artificial intelligence in precision farming to utilizing remote sensing for climate and conservation research, this book lays the groundwork for a data-driven, technology-enabled agricultural future.

Additionally, the narrative highlights the enduring relevance of traditional knowledge, as seen in discussions on millets in India, while also addressing advancements in biotechnology, soil and crop residue management, aquaculture health, and green manuring. The book confronts pressing environmental and physiological challenges, including agricultural pollution, plant responses to water stress and seed dormancy mechanisms.

Whether you are a student, researcher, policymaker or practitioner, this book provides a comprehensive and insightful perspective on the current state of agriculture and its future trajectory. It serves as both a valuable resource and a source of inspiration, urging readers to think creatively and act responsibly in shaping the future of farming.

We hope this compilation not only enriches your understanding of contemporary agricultural innovations but also fosters further inquiry and collaboration across disciplines and sectors.

Editors
Agriculture 2.0: Innovations in the Modern Farming

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ROLE OF ICT AND FPO IN AGRICULTURE

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1. Introduction

Agriculture is not only an economic activity but also a way of life for millions of farmers in India. According to the Census of 2011, more than 86% of farmers in India are small and marginal, cultivating less than two hectares of land. These farmers face multiple challenges such as low yields, dependence on monsoon rain, lack of institutional credit, poor market linkages, and limited access to technology. The situation often results in distress sales, income instability, and rural poverty.

Information and Communication Technology (ICT) has emerged as a powerful tool for transforming agriculture by improving access to information, markets, and services. Mobile phones, internet connectivity, and digital platforms have created opportunities for real-time communication between farmers, extension agents, government institutions, and private players. ICT-based solutions offer weather advisories, crop recommendations, pest control measures, and market price updates, thereby reducing risks and increasing efficiency.

Parallelly, Farmer Producer Organizations (FPOs) have gained importance as institutional mechanisms that empower farmers to act collectively. By pooling resources, farmers can access economies of scale in input procurement, production, value addition, and marketing. FPOs, supported by agencies like NABARD (National Bank for Agriculture and Rural Development), SFAC (Small Farmers' Agribusiness Consortium), and state governments, are emerging as the backbone of rural farmer empowerment.

When combined, ICT and FPOs offer a unique model for inclusive agricultural growth. ICT tools can help FPOs manage records, access markets, and improve transparency, while FPOs can act as last-mile institutions to deliver ICT services to farmers. This synergy creates opportunities for sustainable, climate-resilient, and market-oriented agriculture.

2. Role of ICT in Agriculture

2.1 Market Information Systems

ICT platforms provide farmers with real-time access to market prices and demand conditions. Applications such as **e-NAM**, **Agri-Market App**, and SMS-based services enable farmers to decide when and where to sell their produce, reducing the role of middlemen. This helps increase farmers' share in the consumer rupee.

2.2 Weather and Climate Services

ICT facilitates timely dissemination of agro-weather forecasts through mobile alerts,community radio, and mobile apps. The **India Meteorological Department (IMD)** and platforms like **Kisan Suvidha** provide weather-based advisories, helping farmers take informed decisions on sowing, irrigation, and pest management.

2.3 Digital Financial Inclusion

Mobile banking, UPI, Aadhaar-enabled payment systems, and mobile wallets have revolutionized access to credit and subsidies. Farmers can now receive direct benefit transfers (DBT) under schemes such as PM-KISAN, and FPOs can manage financial transactions digitally.

2.4 Precision Farming and Smart Agriculture

Advanced ICT tools like drones, IoT devices, Geographic Information Systems (GIS), and Artificial Intelligence (AI) are being increasingly used in agriculture for crop monitoring, soil health assessment, and efficient irrigation. These tools reduce input costs and increase productivity.

2.5 Capacity Building and Extension Services

ICT-based platforms, including YouTube tutorials, WhatsApp farmer groups, and e-learning portals, have emerged as effective tools for farmer training and knowledge dissemination. The **Kisan Call Centre (1800-180-1551)** connects farmers with agricultural experts to solve field-level problems in real time.

3. Farmer Producer Organizations (FPOs)

3.1 Concept and Definition

An FPO is a collective of farmers registered under the Companies Act or Cooperative Societies Act, with the objective of enhancing farmers' collective bargaining power. The Small Farmers' Agribusiness Consortium (SFAC) defines an FPO as an institution of primary producers that helps them leverage collective strength to access inputs, technology, and markets.

3.2 Importance of FPOs

- Aggregation of produce to achieve economies of scale.
- Collective procurement of quality seeds, fertilizers, and pesticides at lower costs.
- Strengthening market linkages by reducing dependence on middlemen.
- Facilitating access to government schemes and institutional credit.
- Promoting value addition and processing for better price realization.

3.3 Policy Support

The Government of India launched the **Central Sector Scheme for Formation and Promotion of**

10,000 FPOs (2020–2025) to strengthen farmer institutions. NABARD, SFAC, and state agencies act as implementing bodies, providing financial, technical, and managerial support to FPOs.

4. ICT as a Catalyst for FPOs

4.1 Digital Platforms for Procurement and Marketing

ICT enables FPOs to procure inputs online at competitive rates and sell produce through digital platforms. E-commerce platforms such as **AgriBazaar**, **Ninjacart**, and **DeHaat** link FPOs directly with buyers, eliminating intermediaries.

4.2 Blockchain for Transparency

Blockchain-based solutions offer traceability in supply chains, ensuring food safety and fair payments. By using digital ledgers, FPOs can enhance transparency in transactions, boosting farmers' trust.

4.3 Financial Management

Digital accounting tools and enterprise resource planning (ERP) software help FPOs maintain financial records, track transactions, and prepare reports, thereby improving governance.

4.4 Capacity Building through ICT

Mobile apps, video conferencing, and online training modules enhance the managerial and leadership skills of FPO members. ICT facilitates peer-to-peer knowledge sharing and continuous learning.

5. Case Studies

5.1 e-NAM and FPO Linkages

The Electronic National Agricultural Market (e-NAM) integrates wholesale markets across India. Several FPOs have successfully used e-NAM to sell produce directly to distant buyers, reducing marketing costs and ensuring better prices.

5.2 NABARD's Digital FPO Initiatives

NABARD has promoted digital record-keeping among FPOs by introducing simple mobile-based software for accounting, input procurement, and market linkages.

5.3 Private Agri-Tech Startups

Startups like **AgroStar**, **BigHaat**, and **Samunnati** provide ICT-enabled services to FPOs for input procurement, advisory, and credit linkages. These models demonstrate how digital technologies can integrate smallholder farmers into modern value chains.

6. Challenges and Limitations

- **Digital Divide**: Many rural areas still lack adequate internet connectivity and digital literacy.
- **Financial Constraints**: High costs of ICT infrastructure and lack of credit hinder adoption.
- **Capacity Issues**: Limited managerial capacity of FPO leaders affects ICT adoption.

- **Trust and Adoption**: Farmers may be hesitant to shift from traditional practices to digital platforms.
- **Sustainability**: Dependence on external funding and lack of revenue models challenge the long-term sustainability of FPOs.

7. Policy Support and Future Prospects

7.1 Government Schemes

- **Digital India Mission** aims to provide internet access to all villages.
- **e-NAM** expansion ensures better market linkages for FPOs.
- **Formation of 10,000 FPOs Scheme** provides financial support for institution-building.

7.2 Future Outlook

- Integration of **AI, big data, and IoT** into FPO operations for predictive analytics.
- Use of **mobile-based digital wallets** for seamless payments.
- Development of **climate-smart ICT tools** to support resilience against climate change.
- Greater collaboration between government, private sector, and NGOs in promoting digital FPOs.

8. Conclusion

The convergence of ICT and FPOs has the potential to revolutionize Indian agriculture by empowering smallholder farmers with knowledge, organization, and market access. ICT provides the tools for real-time information, financial inclusion, and transparency, while FPOs provide the institutional framework for collective action. Together, they can reduce the challenges of fragmentation, exploitation, and inefficiency in agriculture. However, bridging the digital divide, ensuring capacity building, and developing sustainable business models are critical for success. With supportive policies and innovative partnerships, ICT-enabled FPOs can play a transformative role in ensuring food security, farmer welfare, and rural prosperity in India.

References

- FAO. (2020). *Information and Communication Technology (ICT) in Agriculture: A Report of the Food and Agriculture Organization*. Rome: FAO.
- Government of India. (2020). *Central Sector Scheme on Formation and Promotion of 10,000 Farmer Producer Organizations*. Ministry of Agriculture and Farmers Welfare.
- NABARD. (2019). *Farmer Producer Organizations: Development and Financing*. Mumbai: NABARD.
- SFAC. (2018). *Guidelines for Farmer Producer Organizations*. New Delhi: Small Farmers' Agribusiness Consortium.
- World Bank. (2019). *ICT in Agriculture: Connecting Smallholders to Knowledge, Networks, and Institutions*. Washington, DC: World Bank.
- Singh, S., & Choudhary, R. (2021). Role of ICT in strengthening Farmer Producer Organizations in India. *Journal of Rural Development*, 40(3), 456–472.

AEROPONICS: FROM MIST TO SUSTAINABILITY

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Abstract

Aeroponics is an innovative soilless cultivation method where plant roots are suspended in air and periodically misted with a nutrient solution, enable rapid growth in a controlled, humid environment without soil. This technique offers substantial advantages over traditional and other soilless farming systems, such as precise management of humidity, temperature, pH, and water conductivity, often under greenhouse conditions. By utilizing vertical and cubic space, aeroponics allows for cultivation nearly anywhere, maximizing resource efficiency and flexibility. Unlike conventional agriculture, aeroponic systems keep roots exposed in specially designed chambers or containers, ensuring optimal oxygenation and moisture for healthy nutrient assimilation and faster, more balanced plant development. The system is highly user-friendly, facilitating simple monitoring, easy maintenance and straightforward harvesting because each plant is isolated, with roots free from soil or standing water. Commercially, aeroponics has enabled the successful cultivation of a wide range of crops including potatoes, yams, tomatoes, lettuce, sweet potato, medicinal plants and other leafy greens demonstrating its scalability and productivity in diverse agricultural applications.

Key Words: Aeroponics, Environment, Mist and Soilless

Introduction

Aeroponics has emerged in response to growing environmental challenges such as water scarcity, soil degradation and shrinking arable land driven by rising global food demands and unsustainable agricultural practices. Traditional farming consumes nearly 70% of global freshwater, with much of it wasted through evaporation, runoff and ineffective absorption, contributing to both resource depletion and pollution. As forests vanish and arable land becomes increasingly limited, addressing water conservation and sustainable crop production has become a critical priority.

Aeroponics is a cutting-edge soilless cultivation method where plants are suspended in air and their roots are periodically misted with a nutrient-rich solution in controlled environments such as greenhouses. This technique delivers up to 95% water savings compared to conventional soil-based agriculture and enables precise control over nutrients and microclimate factors, resulting in accelerated plant growth, higher yields and cleaner produce with minimal pesticide use. By minimizing the need for soil and reducing agricultural runoff, aeroponics offers a sustainable, space-efficient and climate-resilient alternative for modern farming, especially in regions facing acute water constraints or urban density.

History of Aeroponics

The origins of aeroponics trace back to the early 20th century, when researchers used air and mist environments to study plant root structures in laboratory settings. Vyvyan and Travell (1953) conducted successful experiments planting apple plants in a misty environment. The term "aeroponics" itself was introduced by F.W. Went (1957), who cultivated coffee and tomato plants in nutrient mist environments. Initially, aeroponics was primarily a research tool for root observation and physiological studies. Its transition to commercial agriculture began in the 1960s and 1980s, with Bruce Briggs advancing air-rooting for horticulture and Richard Stoner patenting the first microprocessor-controlled aeroponics chamber in 1983-the Genesis Machine (Stoner and Schorr 1983). This milestone marked the debut of aeroponics as a feasible commercial system for plant propagation. The following years saw rapid technological progress and public exposure, notably with the Disney Epcot Center showcase in 1982 and the Genesis Growing System's closed-loop innovations in 1985 (Peterson and Krueger 1988). Peterson and Krueger (1988) highlighted the effectiveness of aeroponics compared to other soilless culture techniques, as it allows plants to grow without soil interference. By the late 1990s, NASA adopted aeroponics for space missions due to its extreme water efficiency and suitability for zero-gravity environments, accelerate research and popularizing the method for both terrestrial and extraterrestrial agriculture (Scoggins and Mills 1998). Additionally, studies have explored modern plant cultivation techniques for medicinal plants, herbs with root-based properties and ornamental horticultural plants (Burgess *et al*., 1998; Scoggins and Mills 1998). Recent decades have seen aeroponics flourish globally as a solution for sustainable crop production, medicinal plant cultivation and efficient urban farming. Distinguished by its efficient use of water, rapid nutrient delivery and ease of harvesting, aeroponics has redefined the boundaries of modern agriculture, contribution new tools for research and solutions for food security (Lakhiar *et.al*., 2020).

AEROPONICS GROWING SYSTEM

Aeroponics is recognized as one of the fastest methods of seed multiplication. In this system, an individual potato plant can produce over 100 minitubers in a single row, a stark contrast to conventional methods, which typically yield only about 8 daughter tubers in a year. Moreover, using soil in a greenhouse environment typically results in the production of only 5 to 6 tubers per plant over a 90-day period. Another advantage of the aeroponics system is its ability to easily monitor nutrients and pH levels. By providing precise plant nutrient requirements, aeroponics reduces the need for fertilizers and minimize the risk of extreme residues entering the groundwater. Furthermore, the aeroponics system allows for the measurement of nutrient uptake over time under varying conditions. For instance, Barak *et al.* (1996) utilized an aeroponic system to non-destructively measure water and ion uptake rates for cranberries. These findings collectively indicate that aeroponics serves as a valuable research tool for studying nutrient uptake, enabling the monitoring of plant health and the optimization of crops grown in closed environments. Additionally, aeroponics is known for its space efficiency, with plants requiring least room for growth. In contrast to other methods like hydroponics and conventional systems, aeroponics utilizes vertical space more efficiently for root and tuber development. Moreover, the controlled environment of aeroponics minimizes pest and disease occurrences, as plant to plant contact is reduced, leading to better and faster plant growth compared to plants grown in a medium. In case of disease, plants can be swiftly removed from the support structure without affecting adjacent plants. As a result, aeroponics allows for higher plant density (plants per unit area) compared to traditional cultivation forms like hydroponics and soil-based methods. The system also facilitates faster cloning of plants, reducing the labor-intensive steps associated with techniques like tissue culture. Additionally, air-rooted plants can be cloned and transplanted directly into the field without the risk of wilting or leaf loss due to transplant shock. The principles of aeroponics are founded on the concept of cultivating plants with roots suspended in a container filled with a flowing nutrient solution, distinct from hydroponics where roots are submerged in a substrate or soil. This method ensures optimal oxygenation and moisture for the roots, promotes better nutrient assimilation and quicker plant development. Containers used in aeroponics can be stacked vertically and are lightweight and portable, allowing for flexibility in agricultural setup. Within a greenhouse or shade house, plants are arranged in vertical columns and nutrients trickle down through these columns. Primarily, plants require direct sunlight during their vegetative stage, after which this exposure becomes less critical. To provide accommodation this, plant containers are periodically moved, with young plants placed at the top and gradually lowered using a rotational mechanical system. This rotation allows for continuous production without interruptions, creating a non-stop production cycle in the aeroponic system. Nutrition in aeroponics is supplied in a closed circuit, limiting consumption to the quantities absorbed by the plants and resulting in significant water savings. For instance, while traditional land cultivation requires 200 to 400 liters of water to produce a kilogram of tomatoes, hydroponics requires about 70 liters, and aeroponics only needs around 20 liters. Additionally, the enclosed nature of the aeroponic system reduces the labor involved to a series of routine mechanical tasks, which are carried out daily throughout the year. This facilitates rapid skill acquisition for workers compared to the years of experience required in traditional agriculture. Aeroponic equipment is housed in greenhouses or anti hail coverings, depending on the location's latitude, with climate controls ensuring optimal growing conditions and high yields.

Aeroponics technology has been successfully piloted in many African countries, notably Rwanda, Kenya and Uganda, for the efficient production of potato minitubers, helping address critical seed shortages and improve crop yields. In most of the countries its cultivation is gaining importance due to nutritional assessment and the prospect of procuring high yields per unit area in a short growing time (Hirpa *et al*., 2010). An experiment conducted by Chang *et al.* (2012) indicates that aeroponics enhance root activity through targeted nutrient application and controlled stolon growth, which supports the development of robust minitubers even under challenging conditions such as high temperatures and extensive cropping cycles. Presently higher yields along with good quality of minituber seed potatoes have also been obtained in some recent advanced production systems, such as hydroponics (Farran and Mingo-Castel 2006; Chang et al., 2012; Mateus-Rodríguez et al., 2012).

This technique, recognized and practiced globally in regions spanning Africa, Europe, Asia, and the Americas, involves suspending plant roots in air and supplying nutrients via timed mist sprays within greenhouses, thereby remove the need for soil or solid substrates. The term “aeroponics,” derived from Latin for “air” and “work,” aptly describes this soilless, highly controlled method of cultivation. Aeroponics has been shown to produce healthy, uniform, and vigorous potato mini tubers, with yields up to ten times greater than conventional methods-facilities in Rwanda, for example, have increased mini tuber output and reduced production costs, while systems in Kenya have demonstrated significant improvements in seed quality and multiplication rates.

The efficiency, disease management benefits and scalability of aeroponics have made it an important asset for seed potato production, supporting sustainable agriculture and food security in both developing and developed nations.

COMPONENTS OF THE AEROPONICS SYSTEM

Spray Misters, which atomize water through nozzles at high pressure. These nozzles come in various patterns and sizes, with larger ones having higher flow rates but require more pressure to operate. The droplet size ranges from sub-microns to thousands of microns, with different classifications serving different purposes. For example, fine mist droplets (10 to 100 microns) are ideal for high-pressure aeroponics (HPA), while droplets in the 5–50-micron range are suitable for hydro atomization. The ideal droplet size for most plant species is 20–100 microns, with smaller droplets saturating the air and larger ones making better contact with the roots. Droplets larger than 100 microns tend to fall out of the air before reaching the roots, while those smaller than 30 microns remain in the air as a fog, potentially reducing oxygen availability to the roots.

High-Pressure Water Pump High-pressure aeroponics relies on a pump capable of pressurizing water to produce droplets of 20 to 50 microns. Typically, these pumps are diaphragm pumps or reverse osmosis booster pumps that maintain a stable 80 PSI with the required nutrient flow.

pH Meter The optimal pH for plant growth in aeroponics system, where water and nutrients are recycled, ranges from 5.8 to 6.5. monitor pH is critical for nutrient absorption, with nitrogen (N) being best absorbed at pH 6.0, and phosphorus (P) and potassium (K) at 6.25 and above. pH is measured on a scale of 0 to 14, with acidity below 7 and alkalinity above 7. Adjustments using "pH up" and "pH down" are made if the pH is too high or low. Specific pH ranges for some vegetables in aeroponics include cucumber (5.8-6.0), lettuce (5.5-6.5), onions (6.0-7.0), potato (5.0-6.0), spinach (5.5-6.6), tomato (5.5-6.5), and carrots (5.8-6.4).

EC (Electrical conductivity) Electrical conductivity (EC) measures the dissolve nutrients in a solution. Lettuce, for example, thrives with an EC of about 1.6. EC is expressed in milli Siemens per centimeter (m S/cm), with values usually ranging from 1.0 to 2.0 m S/cm for many crops. An EC above 4.0 m S/cm can be harmful to plants, and adjustments in irrigation volume or frequency may be needed to maintain best levels.

Light and Temperature Artificial lighting, such as fluorescent tubes, is essential for plant growth in aeroponics, with recommended intensities of 15000- 20000 lux for vegetative growth and 35000-40000 lux for flowering and fruiting. Temperature control is crucial, with an optimal range of 15°C to 25°C. This can be achieved through air conditioning, exhaust fans, and ventilation. Accurate control of nutrient solution temperature is possible in aeroponics, allowing for modified environmental conditions that are beneficial for plant growth. Misting Frequency and Nutrient Reservoir Aeroponic systems can mist the root system continuously or intermittently. Intermittent misting can save energy and still keep a nutrient-rich environment for the roots between misting. Misting frequency can be adjusted based on light levels or programmed cycles. An ideal misting cycle is 1-2 minutes of misting followed by 5 minutes off. Some systems mist for 10 seconds at 20- minute intervals. Aeroponic systems may have separate nutrient reservoirs or an all-in-one design, with larger systems typically returning nutrient solutions to a separate reservoir to prevent blockage as the root system matures.

Aeroponics Working Method In an aeroponic system, young plants can be raised as seedlings using specially designed lattice pots, or cuttings can be placed directly into the system for rapid root formation. Lattice pots allow the root system to develop down into the aeroponic chamber or channel, where it is regularly misted with nutrients. This method has been extensively used for researching root development in many plant species that are difficult to propagate. The base of the cutting is supplied with high levels of oxygen and moisture in a humid environment, prevent desiccation and promote root formation.

Once established in the aeroponics system, the root system rapidly develops in the chamber or channel. It is critical to maintain the optimum droplet size for highest efficiency. There is a wide range of aeroponic nozzles available, allowing for the selection of a droplet size range that best suits the plant and system used. Droplets smaller than 30 microns tend to remain in the air as 'fog' and are not readily absorbed by the roots. The ideal droplet size range for most plant species is 20 - 100 microns. Smaller droplets saturate the air, maintaining humidity levels within the growth chamber, while larger droplets make the most contact with the roots. Droplets over 100 microns tend to fall out of the air before reaching the roots.

The principles of aeroponics are based on cultivating vegetables without soil, in a container filled with flowing plant nutrition. These conditions allow for better plant nutrition assimilation and balanced development, resulting in faster growth. Plant nutrition is supplied in a closed circuit, limiting consumption to only what is absorbed by the plants, thus saving water. For example, traditional land cultivation requires 200 to 400 liters of water to produce a kilogram of tomatoes, while aeroponics only uses about 20 liters. Aeroponics in Space Feeding astronauts on long-term space missions is a challenge, as storing enough food is not feasible. Processed food also lacks sufficient nutrition for long-term use. NASA has been interested in studying the effects of zero gravity on vegetables since the early years of space travel. Experiments have shown that zero gravity affects nutrient uptake, with some nutrients being absorbed more and others less. This is reliable with the findings of Sun *et al*. (2004), who observed that the aeroponics system led to increased stomatal conductance of leaves, intercellular CO2 concentration, net photosynthetic rate, and photochemical efficiency of leaves.

NASA began examining aeroponics as a means of growing food in space in the late 1990s. Research focused on developing an aeroponics system that could efficiently grow food in a zero-gravity environment. The system would need to be self-contained and efficient in water usage, as well as not requiring a growing medium. In 1999, an inflatable aeroponic growing system was developed for use in space. NASA has stated that aeroponics may be essential for future space missions, including a proposed moon base and manned missions to Mars. The effectiveness of aeroponics in water usage and space necessities makes it a promising technology for space agriculture.

Importance of Aeroponics in Modern Agriculture

Aeroponics is becoming progressively more significant in modern agriculture due to its ability to address key challenges like food security, environmental degradation and urbanization.

1. **Efficient Use of Resources**

- **Water Conservation**: Aeroponics uses up to 95% less water than conventional soil farming and 40% less than most hydroponics, making it critical in regions facing water shortage.
- **Reduced Land Use**: Plants grow vertically, reducing the need for arable land and enabling high-density farming in urban environments.

2. Sustainability and Environmental Impact

- **No Soil Degradation**: eliminates the need for soil, thus avoiding erosion and over-farming.
- **Reduced Chemical Use**: With no soil pests, there's less need for herbicides and pesticides, leading to cleaner, safer food and less environmental runoff.
- **Lower Carbon Footprint**: Local indoor farming reduces transportation emission and supports urban food systems.

3. Climate Resilience

- **Year-Round Production**: Aeroponics operates in controlled environments, unaffected by droughts, floods, or cyclic changes.
- **Consistent Yields**: expected stable harvests help strengthen food supply chains.

4. Urban and Space Agriculture

- **Urban Integration**: Perfect for cities with limited space, it enables rooftop and vertical farms, bringing fresh produce nearer to consumers.
- **Space Missions**: NASA has invested in aeroponics for growing food in space due to its least input needs and efficiency.

5. Improved Crop Growth and Quality

- **Faster Growth Rates**: stable oxygen and nutrient availability can lead to 30–50% faster growth.
- **Higher Nutrient Uptake**: Plants absorb nutrients more efficiently, primarily to better yields and potentially more nutritious food.

6. Innovation and Future Farming

- Aeroponics supports tech-driven agriculture, integrating sensors, automation and AI for precision farming.
- It plays a key role in agriculture, where data-driven, sustainable practice defines the next era of food production.

ADVANTAGES OF AEROPONICS:

- **Rapid Growth & Higher Yields:** Direct exposure to oxygen and mist-delivered nutrients accelerate plant growth and can increase yields substantially-sometimes up to three times faster than traditional farming methods.
- **Water Efficiency:** Aeroponics uses 95–98% less water compared to soil-based farming, and also less

than most hydroponic systems, because water is recycled and loss through evaporation or runoff is minimize.

- **Space Efficiency:** By suspending roots and using vertical stacking, aeroponics systems require far less land up to 98% less, making them suitable for dense urban environments and vertical farming.
- **Clean and Disease-Free:** The absence of soil greatly reduces the risk of soil-borne diseases and pests. Roots are separated and easily inspected, making it easier to identify and remove sick plants, which limits disease spread.
- **Precise Control:** Growers have granular control over environmental conditions, nutrient concentrations, pH and humidity, allowing for tailored optimization of plant nutrition and growth.
- **Year-Round and Predictable:** Indoor aeroponic systems allow for reliable, year-round crop production regardless of weather or climate.
- **Energy and Labor Efficiency:** Automated monitoring and misting reduce manual labor and programmable systems can optimize energy consumption.

CHALLENGES OF AEROPONICS

1. High Initial Capital Investment

- Setup costs for aeroponic systems (LED lighting, climate control, misters, sensors etc.) are significantly higher than for soil or hydroponic systems.
- Return on investment (ROI) can take time, especially for startups without subsidies or large contracts.
- Energy costs (for lighting and climate control) can also be a barrier in regions with high electricity rates.

2. Technical & Operational Complexity

- Requires expertise in:
  - Precision nutrient release
  - System calibration
  - Sensor monitors and automation
- System failure risks: If misters or pumps malfunction, roots can dry out quickly, risk for entire crop.
- Managing humidity and biofilm buildup is more difficult than in hydroponics or soil.

3. Limited Crop Variety (for now)

- Works best for leafy greens, herbs, strawberries, potatoes and microgreens**.**
- Root vegetables, grains, and larger fruiting plants are more demanding due to structural and nutrient delivery constraints.

4. Scalability & Standardization Issues

- While aeroponics scales vertically, large-scale commercial implementation faces challenges in maintaining:

- System redundancy
- Uniform climate across larger conveniences
- Lack of industry standards for systems, materials and nutrient recipes limits widespread adoption.

5. Consumer Awareness & Market Access

- Many consumers still prefer "soil-grown" or don't understand aeroponic produce.
- Labeling**,** certification and pricing need clearer communication to build trust and justify higher prices.

Conclusion

aeroponics stands at the front position of sustainable agriculture, offering a commanding alternative to traditional farming methods. By delivering nutrients directly to plant roots through a fine mist, aeroponics considerably reduce water and land use, minimizes the need for chemicals, and enables healthy plant growth even in urban or resource-limited environments. As the world faces increase challenge from climate change, population growth and dwindling resources, aeroponics provides a resilient, scalable path toward secure and sustainable food production. Embracing this modern technology is not merely an agricultural advance-it's a necessary step toward a more sustainable and food-secure future.

REFERENCES

- Barak P, Smith JD, Krueger AR, Peterson LA (1996). Measurement of short term nutrient uptake rates in cranberry by aeroponics. *J. Plant, Cell, and Environ*. 19:237-242.
- Burgess, T., McComb, J., Hardy, G., and Colquhoun, I. (1998). Influence of low oxygen levels in aeroponics chambers on eucalypt roots infected with Phytophthora cinnamomi. *Plant Disease*, 82(4), 368-373.
- Chang, D. C., Park, C. S., Kim, S. Y., and Lee, Y. B. (2012). Growth and tuberization of hydroponically grown potatoes. *Potato Research*, 55(1), 69-81.
- Farran, I. and A.M. Mingo-Castel (2006). Potato Minituber Production Using Aeroponics: Effect of Plant Density and Harvesting Intervals. *American Journal of Potato Research*, 83: 47-53.
- Hirpa, A., M.P.M. Meuwissen, A. Tesfaye, W.J.M. Lommen, A. O. Lansink, A. Tsegaye and P.C. Struik (2010). Analysis of seed potato systems in Ethiopia. *American Journal of Potato Research*, 87(6): 537-552.
- Lakhiar I A, Gao J M, Syed T N, Chandio F A, Tunio M H, Ahmad F, *et al*. Overview of the aeroponic agriculture – An emerging technology for global food security. *Int J Agric & Biol Eng*, 2020; 13(1): 1–10.

- Mateus-Rodríguez, Stef de Haan, I. Barker and Alfredo Rodriguez Delfin (2012). Response of three potato cultivars grown in a novel aeroponics system for minituber seed production. *Acta Hort.*, 947: 361-367.
- Peterson, L. A., and Krueger, A. R. (1988). An intermittent aeroponics system. *Crop Science*, 28(4), 712-713.
- Scoggins, H. L., and Mills, H. A. (1998). Poinsettia growth, tissue nutrient concentration, and nutrient uptake as influenced by nitrogen form and stage of growth. *Journal of Plant Nutrition*, 21(1), 191-198.
- Stoner, R., and Schorr, S. (1983). Aeroponics versus bed and hydroponic propagation [The process of propagating and growing plants in air]. Florists' Review (USA). *Florists Review*, 173(4477), 1-2.
- Sun, Z., Li, T., Yao, L., Zou, H. (2004). Effects of carbondioxide treatment of root zone on potato growth and photosynthesis by aeroponics culture. *Acta Horticulturae*. Sin., 31 (1), 59–63.
- Vyvyan, M. C., and Travell, G. F. (1953). A method of growing trees with their roots in a nutrient mist. Annual Report. p. 95-98. East Malling Research Station, East Malling, Kent, UK.
- Went, F. W. (1957). The experimental control of plant growth. The experimental control of plant growth. *Ronald Press*, New York, USA.

BACKYARD POULTRY FARMING: A LOW-COST, HIGH-RETURN MODEL FOR EMPOWERING RURAL WOMEN AND PROMOTING SUSTAINABLE LIVELIHOODS

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Abstract

Backyard poultry farming is emerging as a transformative tool for rural development, particularly in empowering women and ensuring sustainable livelihoods. This chapter explores the pivotal role backyard poultry plays in economic upliftment, nutritional security, and self-reliance among rural women in India. By focusing on low-cost inputs and high returns, it offers insights into sustainable poultry practices, local indigenous breeds, and integration with other farming systems. We also highlight case studies, government schemes, and the challenges faced by women in adopting poultry farming, along with solutions and recommendations. This holistic approach underlines how a simple backyard initiative can redefine rural prosperity.

Keywords- Backyard poultry, rural women empowerment, sustainable livelihood, low-cost farming, indigenous breeds, nutrition, self-reliance

1. Introduction

Backyard poultry farming has long been a traditional practice across rural India. However, in recent years, its recognition as a sustainable model for women-led development and nutritional support has increased. It requires minimal investment and infrastructure and can be easily integrated with existing agricultural practices, making it ideal for smallholders and landless families.

2. Role of Rural Women in Poultry Farming: Women are the backbone of backyard poultry in India. They manage feeding, health care, and marketing, often without formal training or recognition. This silent participation significantly contributes to the family income, household nutrition, and education of children. Empowering them with knowledge and resources can double the socio-economic impact.

3. Economic Viability and Return on Investment: The input costs for backyard poultry are significantly lower than commercial poultry. Women can start with 5–10 birds, using kitchen waste as feed. Returns begin within 4–6 months through egg sales, meat, or even hatchlings. A well-managed poultry unit can yield an additional monthly income of ₹3,000–₹7,000.

4. Indigenous Breeds and Sustainability

Indigenous breeds such as Aseel, Kadaknath, Vanaraja, and Gramapriya are preferred for their adaptability, disease resistance, and higher market value. These breeds require minimal intervention and are suited to local climatic conditions, making them sustainable for long-term backyard rearing.

5. Integration with Farming Systems

Poultry can be effectively integrated with other farming systems such as crop cultivation and livestock. Poultry manure serves as rich organic fertilizer, improving soil health. Birds also control pests in farms, reducing the need for chemical pesticides, thereby promoting agroecology.

6. Government Schemes and NGO Initiatives

Schemes like Rashtriya Krishi Vikas Yojana (RKVY), National Livestock Mission, and initiatives by NABARD provide financial and technical support to rural women. NGOs also play a vital role by conducting training, ensuring breed availability, and helping with market linkages.

7. Challenges Faced by Women Poultry Farmers

Despite its potential, women face numerous challenges—lack of access to veterinary care, limited mobility, absence of credit facilities, market exploitation, and gender bias. Many are unaware of government schemes or unable to access them due to illiteracy or social barriers.

8. Solutions and Recommendations

To enhance backyard poultry adoption, the following are suggested: (1) regular training programs, (2) formation of self-help groups (SHGs), (3) provision of low-cost healthcare kits, (4) support for indigenous breeds, and (5) improving market access through FPOs. Gender-sensitive extension strategies are crucial.

9. Conclusion

Backyard poultry farming holds immense promise as a grassroots-level intervention for sustainable rural development. With strategic support, rural women can be empowered to become agri-entrepreneurs, thereby ensuring food security, improving household incomes, and driving inclusive growth in rural India.

References

- Kumaresan, A., Buvanendran, V., & Mohapatra, A. (2008). Role of backyard poultry in rural livelihood. Journal of Livestock Research for Rural Development, 20(11).
- Kumar, S., & Anand, S. (2016). Indigenous poultry farming: A sustainable tool for rural livelihood. International Journal of Science, Environment and Technology, 5(6), 3920-3924.

- Rangnekar, D.V. (2006). Livestock in the livelihoods of the underprivileged communities in India: A review. ILRI (International Livestock Research Institute).
- NABARD. (2020). Model Bankable Project on Backyard Poultry Farming.

EFFECT OF BASE MEDIAS IN GROWING OF THE BASIL CROP IN NFT HYDROPONICS SYSTEM

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Abstract

Hydroponics, particularly the Nutrient Film Technique (NFT), offers a sustainable solution to overcome the challenges of declining arable land, climate variability, and rising global food demand. This chapter investigates the influence of different growing substrates-vermiculite, rock wool, perlite, and clay balls-on the growth and yield performance of basil (Ocimum basilicum) under NFT hydroponics. Results from two seasons revealed that vermiculite, with its high water-holding and nutrient retention capacity, performed best during summer, while rock wool, with its superior air–water balance and drainage, was most effective during the rainy season. These findings emphasize the importance of matching substrate properties with environmental conditions to optimize water and nutrient use efficiency, enhance crop quality, and ensure year-round productivity. The outcomes demonstrated that substrate selection plays a decisive role in maximizing basil yield in hydroponics and provide practical insights for sustainable protected cultivation systems aimed at future food security.

Keywords: Hydroponics, NFT, Growing substrates, Basil, Sustainable agriculture

1.Introduction

The World population projected to reach 9.7 billion by 2050. At the same time, it has been estimated that 50% of the arable land around the world will be unusable for farming (United Nation, 2017). Consequently, food production has to be increased by 110% to meet the high demand. According to United Nations Organization (UN), today many countries are facing food crisis especially in Africa. The food crisis is expected to last to 2050 if the demand will not be covered (Okemwa, 2015). The reasons of the food crisis are due to the climate change that causes droughts, frequent floods. Main reasons are the poverty, soil erosion and land degradation. The poverty in many countries especially in southern Africa, causes reduced food production because of reduced accessibility to irrigation and fertilizer. The degradation and soil erosion due to the traditional farming methods that mainly strips the soil the vitamins and minerals. Field soils are generally unsatisfactory for the production of plants in containers because soils do not provide the aeration, drainage, and water holding capacity required and they need to be pasteurized or fumigated to prevent diseases and weeds.

In view of the above of these reasons, the world requires to invent techniques to improve and increase the productivity of farming systems.

Hydroponics is a science of growing plants using a solution of suitable nutrients instead of soil and considered one of the most innovative agricultural strategies to produce more from less, in order to feed the estimated 11 billion people in the world by 2100 (Lal, 2016). Many countries across the world such as Holland, Spanish, German, Canada, United States, Singapore, Taiwan, Japan, China, Newzeland and Australia are shifting their agriculture from soil to soilless culture. Different growing media like sand, perlite, gravel, cocopeat, or sawdust perform mechanical substitutes of soil in hydroponics cultivation. Non-soil growing media can be used to provide mechanical support to the roots which support the plant's weight and hold it upright (Gaikwad and Maitra, 2020). These provide maximum exposure of roots to nutrient solution in a hydroponic structure. Media like cocopeat has a distinct quality for holding water for a longer period and has anti-fungal proper ties. It provides ample microclimate conditions in the root region of plants and increased their height, the number of leaves, and fresh biomass components (Sarkar et al., 2021). The plants thrive on the nutrient solution alone. The growing media, if any, is totally inert and merely acts as a support for the plants and their root systems, while the nutrient solution passes freely. Though, growing media plays an important role in seed germination, seedling growth and vigour in hydroponics. Among factors affecting hydroponics production systems, the nutrient solution is considered to be one of the most important determining factors of crop yield and quality (Trejo-Tellez and Gomez-Merino, 2012).

The purpose of this chapter to focuses on understanding how various growing substrates influence seed germination, seedling vigor, plant development, and yield in the NFT hydroponics cultivation system. The objective is to identify suitable media that enhance nutrient and water use efficiency, improve crop quality, and ensure sustainable hydroponic cultivation of basil, thereby contributing to future food security under limited arable land and changing climatic condition

2. Nutrient Film Technique

NFT has recently become quite popular among growers because of its precise nutrient control, quick turnaround between harvests, and low installment cost (Rabiya, 2012).

The reservoir (tank) was placed at the bottom of the A-frame (**Fig.1),** connected to the top of the rectangular channels by a pump. The nutrient solution was pumped up from the reservoir to the top channel of the frame with 0.1 hp electric pump. The channels were sloped slightly in zig-zag manner and all channels were connected at the ends so that the nutrient water flows from top channel to the bottom channel. The nutrient solution flows from one side to another side of channel, the surplus nutrient solution will stream/flow out of this pipe and move into bottom channel or tube, and finally to the solution tank/reservoir where it is recirculated through the system again. The plants were transplanted in net cups with growing media into holes provided in the top of the tube (growing channels). The roots of the plants were suspended down to the channel where they make contact with the shallow film of the nutrient solution. The shallow film of the nutrient solution allows the plants to absorb nutrients and have access to oxygen in the air without being water logged. The shallow nutrient solution flows all the way through each of the channel having plants in it to the other side, passing by each plant and wetting the roots on the bottom of the channel (Rani *et.al,* 2022).

Fig.1 A-frame Nutrient Film Technique system and after transplantation of basil crop

After completion of each season crop, NFT channels were cleaned to prevent any pathogens moving on to next crop. For cleaning the channels, make up mixture of water with a half cup of bleach was added to kill organisms and then rinsed with fresh water. Cleaning the channels will not transport bacteria or pathogens from one crop to the next.

2.1 Advantages of NFT

The main advantage of NFT is its simplicity and environmental friendliness. This system is well suited for beginners, as the system is easy to control and in case of a problem, it is possible to quickly diagnose where the fault lies. Additional benefits: Minimum growth of medium requirements. low intake of nutrients and water. As the roots can be accessed easily, it is simple to assess the health of the plants. Since water is moving, there aren't many salt deposits. The system can be easily expanded to accommodate many more growth trays. environmentally benign because there is no chance of contaminating groundwater. It is very simple to construct.

2.2 Disadvantages of NFT

NFT's disadvantage is that not all plants can use it, and small technical problems such as a broken pump or clogged drainage pipes quickly turn into major issues. Water needs to be constantly flowing. Even a minor technical error might have disastrous results. Large and heavy plants require adequate stability and support. High amounts of direct sunlight might harm the roots by heating the growing pots. Roots could block the drain.

2.3 Maintaining an NFT Hydroponic System

To ensure the optimal growth of plants, regular monitoring is necessary in NFT hydroponics. Check the nutrient solution levels, pH balance, and nutrient strength regularly. Adjust these factors as needed to maintain ideal conditions for plant growth. Regular monitoring also allows us to identify and address any potential issues early on.

3. Growing media

Hydroponics is a technology for growing plants in nutrient solution with or without the use of artificial media (sand, gravel, vermiculite, rockwool, perlite, peat moss, or sawdust) to provide mechanical support (Musa, 2019). In a hydroponics cultivation system, the interaction between the plant, growing medium, and nutrient solution determines the efficacy of the growing environment (Roosta and Afsharipoor, 2012). The most important factors governing the interaction between a growing medium and the nutrient solution are porosity, water holding capacity, water availability, buffering capacity, and cation exchange capacity (CEC) (Woottan-Beard, 2019). Four types of growing media, namely rock wool, clay balls, perlite and vermiculite were explained in detail.

3.1 Rock wool

Rock wool is among the most widely used media in hydroponics (melted balsamic rock spun into fibre). It is biologically and chemically inert, making it free of any potential pests, diseases and weed seeds (Putra and Yuliando, 2015). It is an inert substrate for both free drainage and re-circulating systems. It is produced by aerosolization of molten mineral compounds which results in a fibrous medium accessible to capillary action that is not degraded by microbiological activity. It has a large water retention capacity and also holds sufficient air. It holds a lot of water which gives an advantage against power or equipment failures shown in **Fig.2.**

Fig.2 Rock wool

Fig.3 Clay balls (Hydrotons)

3.2 Clay balls (Hydroton)

Hydroton or expanded clay aggregate are suitable for hydroponic systems in which all nutrients are carefully controlled in water solution. It is made by baking the clay pellets and known under the trade name of 'Hydroton' or LECA (lightweight expanded clay aggregate). The clay pellets are inert, pH neutral and do not contain any nutrient value. The clay is formed into round pellets and fired at high temperatures (1200 ˚C) in rotary klins. This makes the clay to pop-up and become porous. The main advantage of hydroton is it is light in weight and does not compact over time. This is an ecologically sustainable and reusable growing medium because of its ability to be cleaned and sterilized by washing in solutions of white vinegar, chlorine bleach or hydrogen peroxide and rinsing completely. But there is an opinion that clay pebbles are best not re-used even when they are cleaned due to root growth which may enter the medium shown in **Fig.3**.

3.3 Perlite

The perlite originates from a silicone mineral which forms in volcanoes and is very light in weight (Hussain *et al.,* 2014). It holds less water and more air. It is a fusion of granite, obsidian, pumice and basalt (George and George, 2016). Perlite is a porous substance it offers excellent water retention and drainage capabilities both important in hydroponics. Perlite is an inert and sterile medium which means it's safe to use without the fear of tracking in pests, and which is always the risk with soil. Perlite is made from volcanic rock after being superheated into very lightweight expanded glass pebbles. It is used either loose or in plastic sleeves immersed in water. It is also used in potting soil mixes to decrease soil density and facilitates drainage shown **Fig.4.** If not contained, it can float if flood and drain feeding is used. It is a fusion of granite, obsidian, pumice and basalt. This volcanic rock is naturally fused at high temperatures undergoing what is called "Fusionic Metamorphosis".

Fig.4 Perlite

Fig.5 Vermiculite

3.4 Vermiculite

Like perlite, vermiculite is another mineral that has been superheated until it has expanded into light pebbles. Vermiculite holds more water than perlite and has a natural "wicking" property that can draw water and nutrients in a passive hydroponic system. If too much water and not enough air surround the plant roots, it is possible to gradually lower the medium's water retention capability by mixing in increasing quantities of perlite. Vermiculite is able to help plants more easily absorb nutrients, including magnesium, calcium, and potassium. It can also be combined with other non-soil materials such as perlite and pumice to create custom hydroponic growing media shown **Fig.5.**

3.5 Properties of substrates

The physical properties like bulk density and porosity of bedding materials used are presented in Table.1. The physical properties of the media reveals that the nuetrient avilable charecteristics to plants. Hence a study is planned to study growth and yield characteristics of Basil in all selected medias.

Table.1 Bulk density and porosity of growing media

Substrates	**Bulk density (kg/m^3)**	**Total porosity(%v/v)**
Vermiculite	90-150	90-95
Perlite	80-120	85-90
Rockwool	80-90	94-97
Expanded clay	600-900	85-90

Source: Pardossi *et al.* (2011)

4. Raising of nursery of Basil crop

For growing of nursery, proportion of 60% cocopeat, 20% perlite and 20% vermiculite is mixed thoroughly. The plug trays having 105 cells of size 2.7 cm in diameter and 3.37 cm depth used to grow nursery. These trays were filled with the premixed cocopeat upto 1½ inches. The sowing was done by placing each seed in a hole at a depth of 0.5 cm and covered with thin layer of cocopeat/growing medium. The trays were watered lightly and placed in a sheltered place. The plastic sheet was covered on the trays up to 3 days, after 3 days the plastic cover is removed and water is sprayed with spray cans in the morning/ evening daily without disturbing the seed. Different stages of nursery was shown in **Fig. 6 to 9**. For growing seedlings in rockwool, rockwool is to soaked for 5 min. The surplus water from the rock wool was drained and then placed on portrays. The seeds were placed in the centre of the rock wool. The seedlings were kept damp condition at room temperature in the germinating area. The temperature around the seedlings was kept at least 13-21 °C at night and up to 25 °C during the day. Spray cans were used to spray water. The trays were then removed from room after three days and kept in a polyhouse.

For making the nursery's nutrition solution, 5 mL of stock solution "A" and 5 mL of stock solution "B" were put into a bucket containing 1 L of water and mixed thoroughly. After 10-15 min the pH of solution was checked, and adjusted to 5.5 to 6.5. If pH is at higher side, added pH down solution drop by drop. After one week, the nutrients solution was sprayed until the plant roots reach the bottom of the cube in about fifteen days. The seedlings were ready for transplanting 15 days after sowing as shown in **Fig.10.**

Fig.6 Filling of portrays for nursery and covering with plastic cover

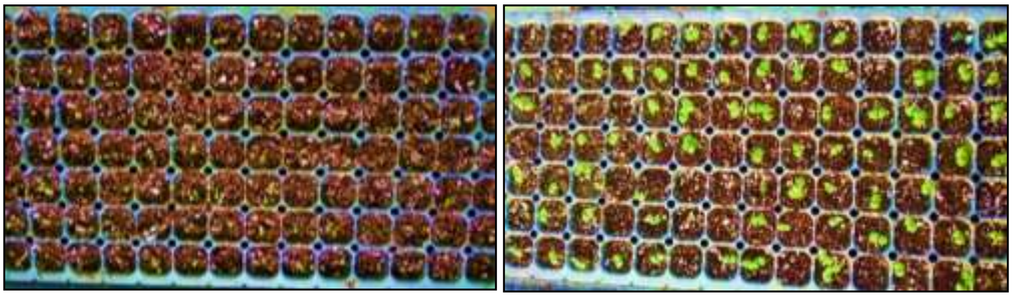

Fig.7 Seedlings emergence after 3 and 5 days after sowing

Fig.8 Basil seedlings after 1 week and 10 days of sowing

Fig.9 Basil after 15 days of sowing

4.1 Transplantation of nursery into NFT channels

Before transplantation, basil seedlings were allowed to reach a height of at least 3 inches. Basil seedlings were ready for transfer after 15 days. The germinated seedlings were transplanted into hydroponic A-frame along with net cups were placed in the platform where thin film of various nutrient solution circulates. The net cups were filled with media (Rock wool, clay ball, perlite and vermiculite) was around the seedling. The plants within net cups that were inserted into the NFT channels as shown in **Fig.10**.

Fig.10 Plant supported with media in net cups and transplantation in NFT channel

5. Growth characteristics of Basil crop in Season1 (April and May)

The graphical representation of 3-D dimensional plot is shown as in **Fig.11.** The 3-D dimensional plot representing the effect concentrated nutrient solution and growing media on the yield. The results showed that 1100 ppm concentrated nutrient solution with vermiculite media gave the highest yield.

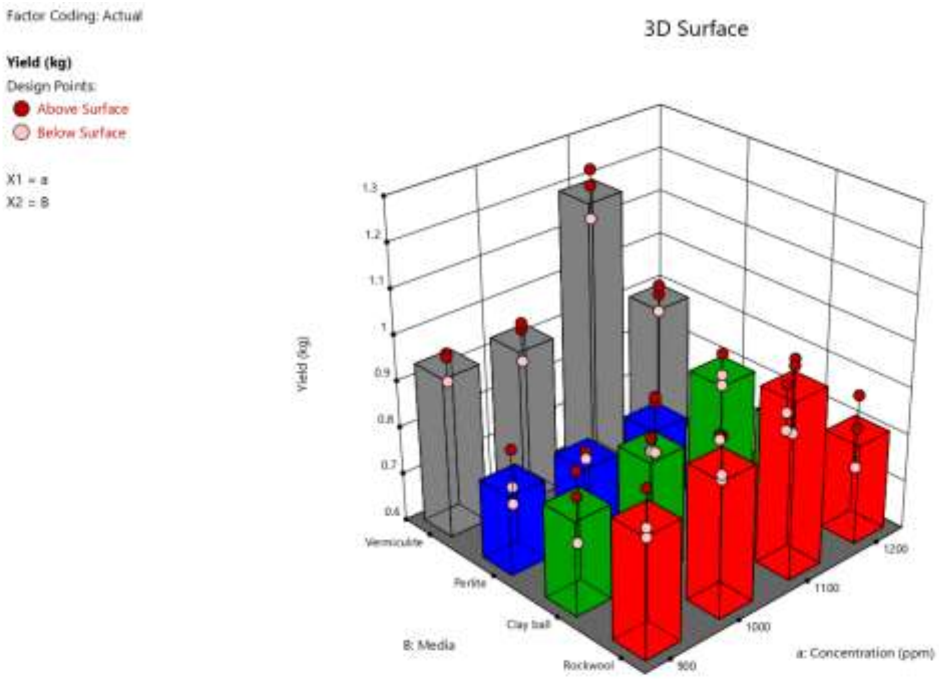

Fig. 11 Effect of nutrient concentration of solution and growing media on yield (Season1)

Rank wise optimum of basil yield for 16 combinations of base medias and concentrations (Season1) is presented in Table 2. Vermiculite gave the highest yield in summer mainly because of its physical and chemical properties that helped basil plants withstand hot and dry conditions in the NFT hydroponic system. Vermiculite performed best in the summer season. The high water-holding capacity of vermiculite retains more moisture than substrates like perlite or clay balls. During summer, when evapotranspiration is high, it provided a consistent supply of water to the root zone, preventing water stress. Temperature Buffering: Its layered structure helps keep the root zone cooler compared to other media, protecting roots from heat damage. Nutrient Retention (CEC – Cation Exchange Capacity): Vermiculite can hold and slowly release nutrients like magnesium, potassium, and calcium. In summer, when nutrient uptake is often hindered by heat stress, this buffering ensured steady nutrient availability. Enhanced Root Growth: The moisture-rich but aerated environment promoted healthy root development, leading to higher vegetative growth and ultimately better yields. Vermiculite's superior moisture retention and nutrient buffering properties allowed basil to overcome summer heat stress, leading to maximum yields.

High water holding capacity of vermiculate induced higher vegetative growth in hydroponics culture of ornamental plants like Oriental hybrid lily (*Liliumasiatic*) (Ryota *et al.*, 2002). Tageteserecta, Salvia splendens, Scaevolaaemula and Verbena hybrida (Strojnv *et al.,* 2004). The higher number of shoots/plants observed in gypsophila grown using sawdust and vermiculite in this investigation could probably be attributed to higher vegetative growth as a result of high-water holding capacity.

Table. 2 Rank wise optimum of basil yield for 16 combinations of base medias and concentrations (Season1)

Number	Concentration	Media	Yield	Desirability
1	**1100**	**Vermiculite**	**1.203**	**0.923**
2	1100	Rockwool	0.986	0.567
3	900	Vermiculite	0.952	0.511
4	1100	Clay ball	0.945	0.499
5	1000	Vermiculite	0.943	0.496
6	1200	Vermiculite	0.909	0.440
7	1000	Rockwool	0.897	0.419
8	900	Rockwool	0.862	0.363
9	1000	Clay ball	0.853	0.348
10	1200	Rockwool	0.819	0.291

11	900	Clay ball	0.807	0.271
12	1200	Clay ball	0.791	0.245
13	900	Perlite	0.774	0.218
14	1100	Perlite	0.768	0.207
15	1000	Perlite	0.757	0.189
16	1200	Perlite	0.648	0.010

5.2 Growth characteristics of Basil crop in Season2 (August to September)

The graphical representation of the equation for the optimization of yield is shown as 3-D dimensional plot in **Fig.12.** The results showed that 1100ppm concentrated nutrient solution with **rock wool** media gave the highest yield. Rock wool is one of the most common substrates in hydroponics, and it gave the highest yield during the rainy season (August–September).

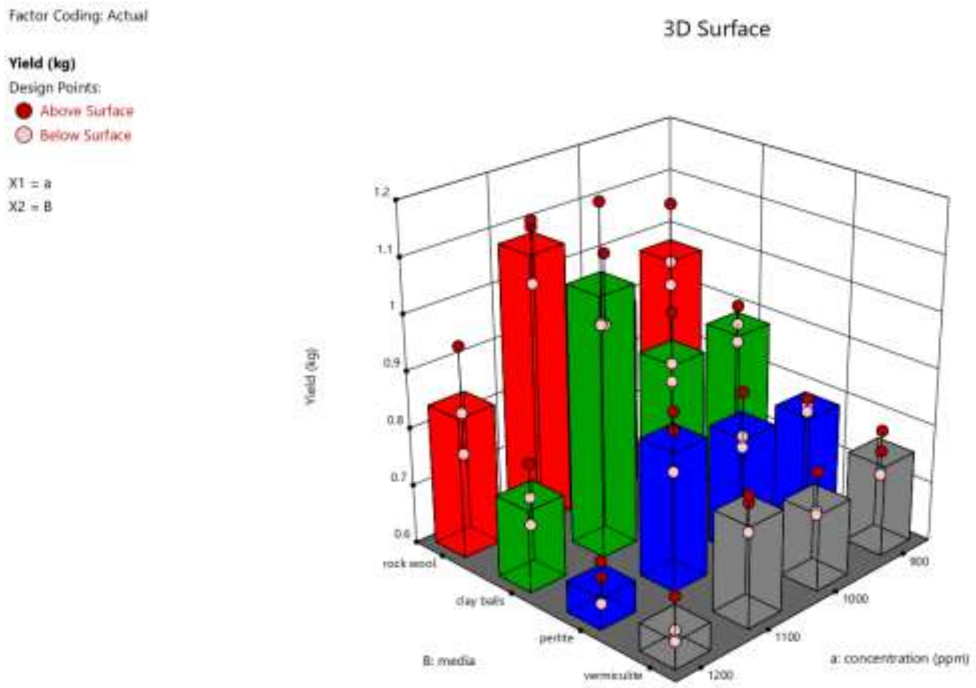

Fig. 12 Effect of nutrient concentration of solution and growing media on yield (Season2)

Rank wise optimum of basil yield for 16 combinations of base medias and concentrations (Season2) is presented in Table 3. Rock wool performed best in the rainy season. Balanced air–water ratio, Rock wool has high porosity (94–97%) and holds both water and air. During the rainy season, when humidity is high and water demand is slightly lower, rock wool prevents excess waterlogging while still supplying enough oxygen to the roots. Stable structure: unlike organic media, rock wool does not compact or degrade. This ensures consistent aeration and root zone stability even under fluctuating rainy-season conditions. Good drainage: In high humidity or excess water situations, rock wool drains well, preventing root suffocation or fungal diseases. Efficient nutrient availability: its inert nature means it does not react with nutrients; thus, the nutrient solution is directly available to the plant. In rainy season conditions, this helps maintain steady nutrient uptake. Rock wool gave the highest yield in the rainy season because its excellent water–air balance and drainage properties matched the environmental conditions, ensuring healthier root systems and better nutrient absorption compared to other substrates. Olle *et al*. (2012) confirmed that the yield of various vegetables tends to be higher for the plants grown in various growing media compared to those grown in the soil. For yield enhancement several authors have recommended growing vegetables in inorganic media (rockwool, sand) rather than organic media. Awang *et.al.*, 2009 studied five types of growing media as 100% cocopeat (T1), 70% cocpeat:30% brunt rice hull (T2), 70% cocopeat: 30 perlite (T3), 70 % cocopeat: 30% kenaf core fiber (T4) and 40% cocopeat: 60% kenaf core fiber (T5). They observed that reduction of pH in the organic based media is associated with a poor roots and use of acid fertilizers. Low EC value indicates that the media did not contain excessive salts that could cause salinity injury but at same time contains insufficient amount of nutrients. The acceptable range of the initial EC of good soilless media should be between (0.4 1.5 mS cm^{-1}).

Table.3 Rank wise optimum of basil yield for 16 combinations of base medias and concentrations (Season2)

Number	con.	Media	Yield(kg)	Desirability
1	**1100**	**Rock wool**	**1.085**	**0.808**
2	1100	Clay balls	1.060	0.765
3	900	Rock wool	0.986	0.638
4	1000	Rock wool	0.938	0.556
5	900	Clay balls	0.895	0.481
6	1000	Clay balls	0.891	0.476
7	1200	Rock wool	0.851	0.406
8	1100	Perlite	0.846	0.397
9	1000	Perlite	0.812	0.339
10	900	Perlite	0.794	0.309
11	1100	Vermiculite	0.779	0.282
12	900	Vermiculite	0.762	0.254
13	1200	Clay balls	0.746	0.225
14	1000	Vermiculite	0.736	0.209
15	1200	Perlite	0.656	0.071
16	1200	Vermiculite	0.649	0.059

6. Conclusion

The study demonstrated that the choice of growing media plays a decisive role in the growth and yield of basil under the NFT hydroponic system. Vermiculite emerged as the most effective substrate during the summer season due to its superior water-holding capacity, nutrient retention, and ability to buffer heat stress, ensuring consistent moisture and nutrient availability for the crop. Conversely, rock wool proved most suitable during the rainy season, as its excellent air–water balance, high porosity, and efficient drainage supported healthy root development and minimized the risks of waterlogging under high humidity conditions. These findings clearly indicate that substrate selection must be optimized based on environmental conditions to maximize productivity.

Overall, NFT hydroponics with carefully chosen substrates offers a sustainable, resource-efficient alternative to conventional soil-based cultivation. By enhancing water and nutrient use efficiency, ensuring year-round production, and providing resilience to climate variability, hydroponics holds significant promise for addressing food security challenges in the future. The outcomes of this study can guide farmers, researchers, and policymakers in advancing protected cultivation systems for basil and other high-value crops.

References

- United Nation, “World population projected to reach 9.8 billion in 2050, and 11.2 billion in 2100,” United Nation, 21 June 2017. [Online]. Available: https://www.un.org/development/desa/en/news/population/world-population-prospects-2017.html
- Okemwa, E. 2015. Effectiveness of aquaponic and hydroponic gardening to traditional gardening. *International Journal of Scientific Research and Innovative Technology*. 2(12):21-52.
- Lal, R. 2016. Feeding 11 billion on 0.5 billion hectare of area under cereal crops. Food and Energy Security. 5: 239-251.
- Gaikwad, D. J., & Maitra, S. 2020. Hydroponics Cultivation of Crops. In Protected Cultivation and Smart Agriculture (pp. 279-287), https://doi.org/10.30954/NDP-PCSA.2020.31.
- Sarkar, M. D., Rahman, M., Uddain, J., Quamruzzaman, M., Azad, M. O., Rahman, M. H., & Naznin, M. T. 2021. Estimation of Yield, Photosynthetic Rate, Biochemical, and Nutritional Content of Red Leaf Lettuce. (F. H. Reboredo, Ed.) Plants, 10(6)(1220). Retrieved from https://doi.org/10.3390/plants10061220
- Trejo-Tellez, L. I., & Gomez-Merino, F. C. 2012. Nutrient Solutions for Hyfroponics Systems. In T. Asao, Hydroponics-A Standard Methodology for Plant Biological Researches (pp. 1-22). Mexico: Intech.
- Rabiya, A. H. 2012. Nutrient Film Technique as a Hydroponic System: A practical guide to grow your own plants easy, healthy, fresh and low cost. CreateSpace Independent Publishing Platform.
- Rani, R.S., Kumar, H.H., Mani, A., Reddy, B.S. and Rao Ch, S. 2022. Cultivation of Basil under Hydroponics with Nutrient Film Technique in Controlled Environment. *Ecology, Environment and Conservation*, *28*, pp.237-242.

- Musa, A. 2019. Hydroponic-farming. Retrieved from https://agriculturistmusa.com/: https://agriculturistmusa.com/hydroponic-farming/
- Roosta, H. R. & Afsharipoor, S. 2012. Effects Of Different Cultivation Media on Vegetative Growth, Ecophysiological Traits and Nutrients Concentration In Strawberry Under Hydroponic and Aquaponic Cultivation Systems. Advances in Environmental Biology, 6, 543-555.
- Woottan-Beard, P. 2019. Growing without soil: An overview of hydroponics. Farming Connect, Aberystwyth University.
- Putra, P.A. and Yuliando, H. 2015. Soilless culture system to support water use efficiency and product quality: a review. *Agriculture and Agricultural Science Procedia*. 3: 283-288.
- Hussain, A., Iqbal, K., Aziem, S., Mahato, P. and Negi, A.K. 2014. A review on the science of growing crops without soil (soilless culture)-a novel alternative for growing crops. *International Journal of Agriculture and Crop Sciences*. 7(11): 833-842.
- George, P. and George, N. 2016. Hydroponics-(Soilless Cultivation of Plants) For Biodiversity Conservation. *International Journal of Modern Trends in Engineering and Science*: *3*(6): 97-104.
- Pardossi, A., Carmassi, G., Diara, C., Incrocci, L., Maggini, R. and Massa, D. 2011. Fertigation and substrate management in closed soilless culture. *Pisa: University of Pisa.*
- Awang Y, Shaharom A. S, Mohamad R. B, Selamat A. 2009.Chemical and physical characteristics of coco pit-based media mixtures and their effects on the growth and development of celosia cristata. *American Journal of Agricultural and Biological Sciences*. 4(1):63-71.
- Ryota, T., Kazunori, M., Musao, T. and Kazuyoshi, S. 2002. Studies on the hydroponics of oriental hybrid lily. *Journal of the Niigata Agricultural Research Institute*. 5: 65-74.
- Strojny, Z. and Nowak, J.S. 2004. Effect of different growing media on the growth of some bedding plants. *Acta Hort.* 644: 157-162.
- Olle, M., Ngouajio, M. and Siomos, A. 2012. Vegetable quality and productivity as influenced by growing medium: a review. *Agriculture*. 99(4): 399-408.

NUTRITIVE VALUES OF MILLETS

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Introduction

Millets are among the oldest food grains known to humankind and have been cultivated for several thousand years, particularly in Asia and Africa. In India, they formed the backbone of traditional farming and food systems, especially in dryland and rainfed regions. These crops are often called "nutri-cereals" because of their rich nutrient content and health-promoting qualities. For centuries, millets sustained rural populations by providing food security under conditions where other cereals such as rice and wheat could not thrive.

One of the most remarkable features of millets is their adaptability to harsh environments. They require little water, tolerate poor soils, and can withstand drought and high temperatures. This resilience makes them valuable not only for farmers in marginal areas but also for global food systems facing the challenges of climate change. Unlike high-input crops, millets grow well with minimal fertilizers and pesticides, making them environmentally sustainable as well as cost-effective for smallholder farmers.

Nutritionally, millets offer a balanced package of energy, proteins, vitamins, minerals, and dietary fiber. They are superior to polished rice and refined wheat in many aspects. For example, finger millet is exceptionally high in calcium, pearl millet is rich in iron, and foxtail millet provides a good amount of dietary fiber and antioxidants. These grains are also known for their low glycemic index, which helps in the slow release of glucose into the bloodstream. As a result, millets are increasingly recommended for people with diabetes, obesity, and other lifestyle-related health problems. In addition to macronutrients and micronutrients, millets contain bioactive compounds such as phenolic acids and flavonoids, which act as natural antioxidants. These compounds help reduce oxidative stress in the body, thereby lowering the risk of chronic diseases like heart disease and certain cancers. The presence of resistant starch and soluble fiber further improves gut health by promoting beneficial bacteria.

Globally, there is a renewed interest in millets as part of sustainable and healthy diets. The declaration of 2023 as the International Year of Millets by the United Nations has further strengthened efforts to revive their production and consumption. Governments, researchers, and food industries are now working together to promote millet-based foods, from traditional dishes to modern value-added products, recognizing their dual importance for nutrition and sustainability.

Classification of Millets

Millets are generally categorized into two groups:

Major Millets: Pearl millet (Bajra), Sorghum (Jowar), Finger millet (Ragi)

Minor Millets: Foxtail millet, Little millet, Barnyard millet, Kodo millet, Proso millet, Browntop millet.

Macronutrient Composition

1. Carbohydrates

Carbohydrates are the main nutrient in millets, making up about 60–70% of their weight. Unlike polished rice or refined wheat, the carbohydrates in millets are mostly in the form of complex starches and dietary fiber, which digest slowly and provide a steady release of energy. This property makes them suitable for people with diabetes and obesity, as they help in avoiding sudden spikes in blood sugar. The starch in millets is made up of two fractions—amylose and amylopectin. A higher amylose content, found in several minor millets such as foxtail and barnyard millet, is associated with slower digestibility and a lower glycemic index (GI). This characteristic is particularly beneficial for people suffering from type-2 diabetes, obesity, and metabolic syndrome, since it helps maintain stable blood glucose levels. Another important aspect is the presence of resistant starch in millets. Resistant starch is a type of carbohydrate that escapes digestion in the small intestine and reaches the large intestine, where it acts as a prebiotic. This improves gut health by stimulating the growth of beneficial microorganisms, enhances short-chain fatty acid production, and supports better absorption of certain minerals.

The glycemic response of different millet species varies. For example, barnyard millet and foxtail millet have one of the lowest GI values among cereals, making them excellent choices for diabetic-friendly diets. On the other hand, finger millet and pearl millet, while relatively higher in GI compared to minor millets, still provide more fiber and micronutrients than refined rice or wheat. Besides starch, millets also contain a significant amount of non-starch polysaccharides and soluble dietary fibers. These components slow down gastric emptying, promote satiety, and help in regulating cholesterol levels. Regular inclusion of millet-based foods has been shown to lower LDL cholesterol and triglycerides, thereby reducing cardiovascular risks.

Thus, the carbohydrate profile of millets is not just about providing calories but also about offering functional health benefits. By combining slowly digestible starch, resistant starch, and dietary fiber, millets serve as an ideal energy source that supports metabolic health, digestive well-being, and long-term disease prevention.

2. Proteins

Proteins are the second most important nutrient in millets, generally ranging from 7–12%, depending on the type of millet. Though the total protein content is moderate compared to pulses, the quality of protein in millets is superior to rice and wheat because they contain certain essential amino acids that are often lacking in other cereals. For example, finger millet and pearl millet are good sources of methionine and tryptophan, amino acids important for growth, tissue repair, and nervous system health. These amino acids are usually deficient in rice and maize, making millets a valuable complement in cereal-based diets.

Millet proteins also play a role in slower digestion due to their complex structure, which, along with fiber, contributes to a low glycemic response. This helps in maintaining satiety, supporting weight management, and improving overall metabolic health. Thus, the protein in millets not only adds to daily nutritional requirements but also enhances the biological value of traditional diets, especially when consumed with legumes or pulses, providing a balanced and wholesome source of nutrition.

3. Fats

Millets generally contain a low to moderate amount of fat compared to oilseeds and pulses, but their fat content is higher than that of rice and wheat. The total fat content of millets usually ranges between 3–6%, depending on the type of millet. Most of this fat is in the form of unsaturated fatty acids, which are considered heart-friendly. Finger millet, foxtail millet, and pearl millet have a good proportion of polyunsaturated fatty acids (PUFAs) such as linoleic and oleic acids, which help reduce bad cholesterol and support overall cardiovascular health. Millets also contain small amounts of essential fatty acids that play a role in maintaining cell structure, hormone synthesis, and nutrient absorption. Because of their higher lipid content, millet grains are slightly more prone to rancidity during long storage compared to polished rice. However, these natural fats contribute to better energy supply, improved palatability, and nutritional balance in diets, making millets a valuable part of healthy food systems.

4. Dietary Fiber

Millets are an excellent source of dietary fibre, which is much higher than that of refined cereals like rice and wheat. On average, millets provide 8–12% fibre, though some types like finger millet and pearl millet may have even higher levels.The fibre in millets includes both soluble and insoluble fractions. Insoluble fibre improves bowel movement, prevents constipation, and supports gut health, while soluble fibre helps regulate blood sugar and lowers cholesterol. Because of this, regular millet consumption is linked with reduced risk of diabetes, obesity, and cardiovascular diseases. High fibre content in millets also contributes to satiety, keeping one fuller for longer and aiding in weight management. Thus, millets are rightly recognized as a functional food for promoting digestive and metabolic health.

Micronutrient Composition

Millets are unique cereals because they provide not only energy and dietary fiber but also a wide spectrum of minerals that are often lacking in rice and wheat-based diets. These minerals play critical roles in maintaining human health, preventing deficiencies, and supporting overall growth and development.

1. Minerals: Millets are rich in essential minerals such as:

Calcium: Calcium is one of the most important minerals for bone development, muscle function, and nerve signaling. Among cereals, finger millet (ragi) is exceptionally rich in calcium (344 mg/100 g), often containing 10 times more calcium than rice or wheat. Regular inclusion of finger millet in diets is especially beneficial for children, women, and elderly people, as it helps prevent rickets, osteoporosis, and joint weakness.

Iron: Iron is required for hemoglobin formation and oxygen transport in the body. Pearl millet is considered a powerhouse of iron, with levels much higher than most common cereals. This makes it valuable in combating iron-deficiency anemia, which is widespread in India. Consuming iron-rich millets along with vitamin C-rich foods further improves its absorption

Magnesium: Millets such as foxtail and little millet are good sources of magnesium. This mineral plays a role in regulating blood pressure, supporting heart health, and aiding more than 300 biochemical reactions in the body. Magnesium deficiency is linked with diabetes, hypertension, and muscle cramps, so millet-based diets can naturally help in managing these lifestyle disorders.

Phosphorus: Phosphorus works together with calcium to build strong bones and teeth. It is also essential for energy metabolism and maintaining the structural integrity of cell membranes. Millets, particularly barnyard millet, provide a healthy amount of phosphorus, which supports tissue repair and growth in growing children and physically active individuals.

Zinc: Zinc is a trace element but very important for immune system function, reproductive health, and enzyme activity. Deficiency of zinc can cause stunted growth and poor wound healing. Many small millets, such as kodo millet and little millet, provide zinc in adequate amounts, making them useful for enhancing immunity, especially among children and pregnant women.

Copper: Copper is required in very small quantities, but it plays a vital role in iron absorption, red blood cell production, and antioxidant defense mechanisms. Millets naturally contain copper, which supports metabolism and strengthens immunity. Regular intake can prevent copper deficiency-related problems like fatigue, weak bones, and anemia.

2. Vitamins

Millets are not only rich in minerals and dietary fiber but also contain a good range of vitamins that play a vital role in human health. They are especially known for their content of B-complex vitamins, which are essential for energy metabolism and maintaining a healthy nervous system.

- Vitamin B1 (Thiamine): Found in pearl millet and finger millet, it supports carbohydrate metabolism and helps in proper functioning of the heart and nerves.
- Vitamin B2 (Riboflavin): Present in small amounts in different millets, it aids in energy production and improves skin and eye health.
- Vitamin B3 (Niacin): Foxtail millet and pearl millet are good sources of niacin, which helps in cholesterol control and supports the digestive system.
- Vitamin B6 (Pyridoxine): Important for protein metabolism and brain development, present in moderate levels in most millets.
- Folate (Vitamin B9): Finger millet contains folate which is essential for red blood cell formation and is particularly important for pregnant women.
- Vitamin E: Some millets like foxtail millet have small quantities of vitamin E, which acts as an antioxidant and supports skin health and immunity.

Bioactive Compounds

Millets are not only rich in nutrients like carbohydrates, proteins, vitamins, and minerals but also contain several bioactive compounds that make them highly beneficial for human health. These compounds act beyond basic nutrition and help in disease prevention, improving immunity, and promoting overall well-being.

Some important bioactive compounds in millets are:

- Polyphenols – Millets are a good source of phenolic acids, flavonoids, and tannins. These act as natural antioxidants, protecting the body from harmful free radicals and reducing the risk of chronic diseases like diabetes, cancer, and cardiovascular problems.
- Phytosterols – Present in small amounts, they help in lowering blood cholesterol levels and maintaining heart health.
- Dietary Fiber – Though considered a nutrient, it also plays a bioactive role by improving gut health, aiding digestion, and regulating blood sugar levels.
- Lignans – Found in the seed coat, these compounds have antioxidant and anti-inflammatory properties, contributing to hormonal balance and reduced risk of hormone-related disorders.
- Saponins – Naturally occurring compounds in some millets that support immune function and

may help in reducing cholesterol absorption.

- Resistant Starch – Acts like dietary fiber, improving satiety, controlling blood glucose levels, and supporting beneficial gut bacteria.

Health Benefits of Millets

1. Diabetes Management: Millets have a low glycemic index, which helps in the slow release of sugar into the bloodstream. This prevents sudden spikes in blood sugar levels and supports better insulin sensitivity, making them ideal for people with type 2 diabetes. 2. Cardiovascular Health: High fiber, magnesium, and unsaturated fats improve heart function.

2. Bone Strength: Finger millet (ragi) is packed with calcium and vitamin D, both essential for healthy bones and teeth. Regular consumption strengthens skeletal structure and helps prevent osteoporosis, especially in children and the elderly.

3. Weight Management: High fiber content in millets promotes fullness and satiety, reducing overeating and unnecessary snacking. This makes them a smart choice for weight loss and long-term weight maintenance.

4. Anemia Prevention: Pearl millet and finger millet are rich in iron and folic acid, which help in boosting hemoglobin levels. They are especially beneficial for women and children prone to iron-deficiency anemia. Eating millets with vitamin C-rich foods enhances iron absorption.

5. Digestive Health: Millets contain resistant starch and insoluble fiber that aid digestion, prevent constipation, and promote the growth of healthy gut bacteria. Being gluten-free, they are also suitable for people with gluten intolerance or celiac disease.

6. Cardiovascular Health: Rich in fiber, magnesium, potassium, and unsaturated fats, millets help reduce bad cholesterol (LDL) and improve good cholesterol (HDL). Magnesium also relaxes blood vessels, lowering blood pressure and reducing the risk of heart disease.

Comparative Nutritional Value of Millets

Millets	Protein (%)	Fat (%)	Fiber (%)	Calcium (mg/100 g)	Iron (mg/100 g)
Finger Millet	7.3	1.3	3.6	344	3.9
Pearl Millet	10.6	5.0	1.2	42	8.0
Sorghum	10.4	3.1	2.0	25	4.1
Foxtail Millet	11.2	4.3	8.0	31	2.8
Little Millet	9.7	4.7	7.6	17	9.3
Barnyard Millet	11.2	3.9	10.1	11	15.2
Kodo Millet	8.3	3.6	9.0	27	0.5
Proso Millet	12.5	2.9	14.2	14	0.8

Conclusion

Millets truly deserve the title of "nutri-cereals" because of their wide-ranging nutritional benefits and adaptability. They are not only a source of energy but also provide vital amino acids, essential minerals like iron, calcium, and magnesium, as well as important vitamins and bioactive compounds that support overall health. Regular consumption of millets can help in combating malnutrition, reducing the risks of lifestyle disorders such as diabetes, obesity, and heart disease, and in improving overall well-being. Moreover, their resilience to harsh climatic conditions makes them an ideal crop for ensuring food and nutritional security, especially in dryland and resource-poor regions. With increasing health consciousness and a global shift towards sustainable diets, millets are steadily regaining importance in modern food systems, emerging as superfoods that promise both human health and environmental sustainability.

Innovations for Sustainable Livestock and Aquatic Production

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This chapter reviews recent scientific and technological advancements in veterinary medicine, animal husbandry, poultry production, and fisheries. Innovations like precision livestock farming, genomics, better breeding techniques, new treatments, welfare-oriented housing systems, and sustainable aquaculture methods are revolutionizing these industries in response to the rising demand for animal-based foods worldwide. These advances not only enhance productivity but also address pressing concerns regarding animal health, climate resilience, and environmental sustainability.

1. Introduction

The livestock, poultry, and fisheries sectors contribute significantly to global food security, rural livelihoods, and the economy. In order to satisfy the growing demand for premium animal products while maintaining environmental stewardship and animal welfare, technological advancement in veterinary science and related sectors is crucial. This chapter outlines the latest innovations and their implications for sustainable production.

2. The sustainability agenda

Environmental: Reduce toxic gases (such as nitrous oxide from manure and methane from animals), maintain clean water, safeguard plants and animals, and enhance the health of the soil and sea.

Economic: Improve resource-use efficiency, reduce losses, diversify income streams, and build shock resilience.

Social: Safeguard worker and animal welfare, ensure food safety, empower women and youth, and enable equitable market access.

Health: Use the One Health strategy to combat antibiotic resistance, enhance nutrition, and manage diseases that can transmit from animals to people.

3. Advances in Veterinary Science

Diagnostic Technologies

Point-of-care diagnostics: Within hours, on-farm identification of avian influenza, brucellosis, mastitis pathogens, and FMD is now possible due to portable PCR, LAMP assays, CRISPR-based detectors, and biosensors. Multiplex cartridges cut down on sample volumes and turnaround times.

Digital phenotyping: Wearable health monitoring devices track temperature, heart rate, and rumination patterns for early disease detection.

Imaging and e-pathology: AI-assisted histology and whole-slide imaging expedite case workups, while handheld ultrasonography and thermal cameras support reproductive and lameness examinations.

Therapeutics and Preventive Medicine

Recombinant, vector and VLP vaccines: Modern vaccine platforms (like HVT in poultry) and plant-based virus-like particles can be quickly updated to match new strains of fast-changing diseases (such as Newcastle disease in poultry). Heat-stable and needle-free vaccines make it easier to reach animals in low-resource areas.

mRNA and DNA platforms: Although they are still relatively new in the veterinary field, experimental mRNA vaccines for fish and agricultural animals demonstrate that they may be developed rapidly, produce robust immunity, and could be extremely useful in outbreak situations.

Adjuvant science and delivery: New vaccine boosters (like saponin, CpG, and nano-emulsions) and advanced packaging methods allow vaccines to be given by mouth or nose in fish and poultry. Long-lasting injections also reduce the need for repeated handling of animals.

Genetic and Reproductive Innovations

Genomic selection and marker-assisted breeding

Using high-density genotyping and genomic estimated breeding values (GEBVs) helps speed up the selection of animals with useful traits like better feed efficiency, disease resistance (e.g., mastitis), heat tolerance, and ability to perform well in low-input systems. Combining family-based selection with genomics improves growth rate, feed conversion ratio (FCR), and resistance to diseases such as Streptococcus and ISAV in fish.

Reproductive technologies

In livestock, artificial insemination (AI) using sexed semen, synchronization of estrus, and embryo transfer aid in regulating reproduction, accelerating generations, and forming the structure of herds and flocks. In fish, induced breeding, hormone-assisted spawning, and cryopreservation make year-round seed availability and selective breeding.

Conservation and utilization of indigenous breeds

In regions with high temperatures, limited input systems, and a high risk of disease, local breeds are frequently superior to exotic ones. Community-based breeding programs (CBBPs) and open nucleus schemes help protect genetic diversity while improving these breeds in their natural environments.

One Health Integration

Integrated surveillance: Integrated surveillance: Linking environmental, human, and animal health data facilitates early identification and targeted action against zoonotic diseases and antimicrobial resistance (AMR).

Stewardship tools: Stewardship tools: Antibiotic misuse can be reduced by using diagnostics, antibiograms, dose calculators, and agreements between veterinarians and farmers. Safe and responsible use is ensured by educating farmers and conducting drug residue tests.

4. Advances in Animal Husbandry

Precision Livestock Farming (PLF)

Sensing ecosystems: Real-time animal data is gathered by devices such as sound detectors, cameras, rumen sensors, collars, and ear tags. AI uses this data to detect heat cycles, calving, hidden mastitis, heat stress, and welfare issues (like tail-biting in pigs).

Automation: Robotic milking, automated feeders and cleaners, and drones for pasture inspections are examples of tools that save labor costs and guarantee reliable management.

Decision support: Digital twins experiment with various breeding and feeding strategies. AI identifies anomalous trends so farmers can take prompt action.

Genetics and breeding

Genomic selection: For qualities including milk yield, fertility, disease resistance, and heat tolerance, genomic selection expedites breeding and increases accuracy.

Gene editing: CRISPR gene editing is used to create heat-tolerant animals, PRRS-resistant pigs, and hornless cattle. Ethical rules, regulations, and public acceptance are key challenges.

Conservation genomics: Preserves native breeds by using cryobanking to safeguard their distinctive characteristics and cultural significance.

Feed and Nutrition: Climate-Smart and Circular Approaches

Alternative and novel proteins

Insect meals: Mealworms and black army flies convert organic waste into protein and fat that can be fed to pigs, fish, and poultry.

Single-cell proteins: Sources like yeast, fungi, algae, and methanotrophs provide balanced amino acids and need very little land to produce.

Aquafeed innovations: Utilizing oilseeds (canola, camelina), fermented blends, and microbial oils high in DHA/EPA reduces the need for fishmeal and increases feed digestibility.

Enteric methane mitigation and rumen modulation

Some feed additives like nitrate salts, tannin-rich plants, essential oils, red seaweed & 3-NOP can lower methane produced in animals. these work best when animals also receive a balanced diet and proper medical care.

Precision feeding and decision support

Advanced ration models, automated feeders, and forage testing (NIRS) help feed animals according to their growth stage (phase feeding), which reduces excess nitrogen and phosphorus waste and lowers feed costs. In fish and shrimp systems (RAS and biofloc), real-time water quality monitoring (TAN, nitrite, alkalinity) helps maintain stable feeding and healthy microbes.

Circular feed resources

Seaweed and aquatic plants like duckweed and azolla, as well as agricultural and industrial by-products including DDGS, oilseed cakes, and fruit pomace, can partially substitute conventional feed. However, harmful compounds in them need to be reduced through methods like fermentation, extrusion, or pelleting.

5. Advances in Poultry Science

Breeding and Genetics

New breeds of poultry that consume less feed but grow more quickly and maintain better health are being developed. Additionally, genetic techniques are improving birds' ability to withstand thermal stress.

Health and Biosecurity

Automatic systems are currently used in modern poultry buildings to regulate ventilation, temperature, and air quality for the comfort of the birds. To protecthens from illnesses like infectious bronchitis and Newcastle disease, new vaccinations are being developed.

Nutrition and Production Efficiency

Adding special enzymes to feed helps birds digest nutrients more effectively. Algae and insect proteins are being investigated as sustainable and environmentally beneficial substitutes for conventional feed.

6. Health, Welfare, and Biosecurity

Preventive health and vaccines

Subunit, recombinant, and DNA/RNA vaccines are among the novel vaccine types under development. When made thermostable, they offer robust protection and can be kept without much refrigeration, which is useful in places with inadequate cold storage. To provide more effective protection, unique "autogenous vaccines" are developed specifically to combat the diseases present on fish and shrimp farms. Appropriate diagnostic testing is now used to guide strategic deworming and external parasite management. This aids in delaying the issue of parasite medication resistance.

AMR stewardship

Use of antibiotics is reduced by relying more on vaccines, better hygiene, and quick diagnostic tools (like LAMP and CRISPR-based tests). Alternatives such as bacteriophages, probiotics, and synbiotics are used instead of antibiotics. Food safety and access to export markets are maintained by adhering to the appropriate withdrawal periods and testing for residues in meat, milk, or fish.

Welfare-centric design

Animal comfort is linked with better productivity and public trust. In poultry, enriched housing, perches, nest boxes, low-stress handling, and shade–mist cooling systems reduce stress. Additionally, humane slaughter practices are used. Humane stunning, graded netting, and appropriate stocking density all contribute to lower mortality rates and higher-quality meat in aquaculture.

Biosecurity layers

Strong biosecurity prevents disease outbreaks. Zoning farms, limiting the movement of people and animals, and enforcing stringent entrance regulations (all-in/all-out systems, clean vs. unclean regions, water disinfection) are important measures. Hatcheries and broodstock centers especially need multi-layered protection since disease risks are very high there.

7. Advances in Fisheries and Aquaculture

Genetic and Breeding Technologies

Shrimp and fish are specifically engineered to develop more quickly and to be more disease-resistant. To create seeds (young fish or shrimp) of significant commercial species, induced breeding techniques are employed.

Sustainable Aquaculture Practices

Biofloc technology and recirculating aquaculture systems (RAS) contribute to waste reduction and water conservation. Integrated Multi-Trophic Aquaculture (IMTA) combines fish, shellfish, and seaweed, so waste from one becomes food for another.

Disease Management

To make disease prevention easier, oral vaccinations are being developed for shrimp and fish. Aquatic species are kept healthy without overusing antibiotics by using probiotics and immune-boosting vitamins, sometimes known as immunostimulants.

Aquaculture effluent management

Excess nutrients from fish farm waste are absorbed by periphyton-based channels and constructed wetlands.

In addition to recycling garbage, IMTA systems generate other products including shellfish and seaweed.

Zero-waste processing

Fish and animal waste, such as offal, bones, or shells, can be recycled into products that are valuable. Examples include generating animal feed and fats by rendering, collagen and gelatin from bones and skin, chitin and chitosan from shrimp and crab shells, and fish silage as a protein-rich foodstuff.

8. Challenges and Future Prospects

Aquaculture and animal husbandry are being improved by new technologies, yet there are still significant obstacles to overcome. Progress is frequently slowed by societal or economic hurdles, emerging and rapidly spreading diseases, climate change, and increased antibiotic resistance. Collaboration between scientists, veterinarians, legislators, and farmers will be essential to future success. Long-term development will depend on increased training, regulations that support it, and a broader adoption of welfare-friendly and sustainable methods.

9. Conclusion

Advances in veterinary medicine, livestock, poultry, and fisheries have the potential to significantly increase productivity, profitability, and sustainability. Achieving a balance between economic growth, public well-being, animal welfare, and environmental protection can be facilitated by implementing these innovations under the One Health approach, which links human, animal, and environmental health.

HARNESSING SOIL MICROBIOMES FOR SUSTAINABLE ORGANIC AND NATURAL FARMING

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Abstract

The transition towards organic and natural farming systems is imperative to meet global demands for sustainable food production while minimizing environmental degradation. Sustainable agriculture has become a global priority in the wake of climate change, biodiversity loss, and soil degradation caused by chemical-intensive farming. Soil microbiomes, the complex communities of microorganisms inhabiting the soil, represent nature's most powerful allies in achieving agricultural sustainability. In organic and natural farming systems, harnessing soil microbiomes ensures nutrient cycling, plant growth promotion, pest suppression, and enhanced resilience to environmental stress. This chapter explores the principles and applications of soil microbiomes in organic and natural farming that can redefine sustainable agricultural practices. It discusses advanced technologies such as microbial genomics, liquid bioconsortia, nanobiotechnology, and CRISPR-engineered beneficial microbes. Case studies and future prospects are also presented, highlighting the transformative role of soil microbiomes in building climate-smart and eco-friendly farming systems.

Keywords- Soil microbiome, Organic farming, Natural farming, Biofertilizers, Biocontrol, Sustainable agriculture, Microbial consortia

1. Introduction

The twenty-first century is witnessing unprecedented challenges in global agriculture, including climate change, soil degradation, biodiversity loss, and food insecurity. According to FAO (2021), over 33% of the world's soils are moderately to highly degraded due to intensive chemical inputs, monocropping, and unsustainable land management practices. These challenges necessitate the transition from input-intensive conventional agriculture to more sustainable systems such as organic and natural farming. Unlike conventional practices, which often rely on synthetic fertilizers and pesticides, organic and natural farming emphasize ecological balance, biodiversity conservation, and soil health restoration (Reganold and Wachter, 2016).

At the heart of these sustainable systems lies the soil microbiome, the complex and dynamic community of microorganisms such as bacteria, fungi, archaea, actinomycetes, protozoa, and viruses that govern essential ecosystem functions. Soil microbes are not merely passive inhabitants but are active participants in nutrient cycling, organic matter decomposition, plant growth promotion, and natural suppression of pests and diseases (Bender, Wagg, and van der Heijden, 2016). Their role is particularly significant in organic and natural farming, where external chemical inputs are minimized, and reliance on biological processes is maximized.

Recent advances in agricultural microbiology and microbial ecology, such as high-throughput sequencing and metagenomics, have revealed the immense diversity and functional potential of soil microbiomes (Bulgarelli *et al.,* 2013). These insights have provided new opportunities to harness soil microbiomes for enhancing nutrient availability, improving crop productivity, and building resilience against abiotic and biotic stresses. Consequently, understanding and managing soil microbiomes has emerged as a cornerstone of sustainable agriculture, offering a science-driven pathway to achieve food security while maintaining ecological balance.

2. Soil Microbiomes: The Living Engine of soil

Soil is often described as a “living entity” because it harbors an incredibly rich and diverse array of microorganisms. The soil microbiome comprises trillions of microbial cells per gram of soil, representing one of the most complex microbial ecosystems on Earth (Fierer, 2017). These microorganisms form intricate networks of interactions that underpin soil fertility and plant productivity. Microbes colonize the rhizosphere, the endosphere, and even the phyllosphere, creating a dynamic continuum between soil, plant, and the surrounding environment.

The soil microbiome plays a pivotal role in biogeochemical cycling. Bacteria such as *Nitrosomonas* and *Nitrobacter* regulate nitrogen transformations, while phosphate-solubilizing microorganisms like *Pseudomonas* and *Bacillus* enhance phosphorus availability. Actinomycetes contribute significantly to the decomposition of complex organic matter, while fungi, particularly Arbuscular Mycorrhizal fungi (AMF), extend the absorptive capacity of roots, facilitating nutrient uptake from otherwise inaccessible pools. Collectively, these processes sustain soil fertility in the absence of synthetic fertilizers, which is fundamental to organic and natural farming systems.

Another essential feature of the soil microbiome is its role in maintaining soil structure and organic matter stabilization. Microbial metabolites, such as extracellular polysaccharides, promote soil aggregation, improve aeration, and enhance water-holding capacity. The decomposition of organic inputs by diverse microbial communities not only recycles nutrients but also contributes to soil organic carbon sequestration, mitigating climate change impacts. Thus, microbial activity provides a dual benefit ensuring crop productivity and contributing to environmental sustainability.

Importantly, the soil microbiome is highly dynamic and responds sensitively to management practices. Intensive tillage, excessive chemical inputs, and monocropping often disrupt microbial diversity and function, while practices such as organic amendments, reduced tillage, crop rotation, and cover cropping enrich microbial populations and promote functional redundancy. This adaptability highlights the importance of managing the soil microbiome intentionally within organic and natural farming frameworks to harness its full potential.

3. Microbial role in organic and natural farming

3.1 Nutrient Cycling

Microorganisms are the primary drivers of nutrient availability in soils. Nitrogen-fixing bacteria, including symbiotic genera such as *Rhizobium* and *Bradyrhizobium*, and free-living diazotrophs like *Azotobacter* and *Azospirillum*, play an indispensable role in replenishing soil nitrogen pools. Similarly, phosphate-solubilizing bacteria (PSB) such as *Bacillus megaterium* and fungi like *Aspergillus niger* release phosphorus from insoluble forms, while potassium- and zinc-solubilizing microbes contribute to the mobilization of essential micronutrients (Sharma *et al.*, 2013). Mycorrhizal fungi enhance plant nutrient uptake by forming extensive hyphal networks, particularly important for immobile nutrients such as phosphorus.

3.2 Plant Growth Promotion

Plant growth-promoting rhizobacteria (PGPR) enhance crop productivity through multiple mechanisms. These include the production of phytohormones such as indole-3-acetic acid (IAA), gibberellins, and cytokinins, which stimulate root proliferation and shoot development (Bhattacharyya and Jha, 2012). PGPR also influence plant stress tolerance by synthesizing enzymes such as ACC deaminase, which lowers ethylene levels under stress conditions. In organic and natural farming systems, these microbes substitute for synthetic growth regulators and fertilizers, aligning with ecological principles.

3.3 Biocontrol of Pests and Pathogens

Soil microbes are central to natural disease suppression. Beneficial antagonistic organisms like *Trichoderma harzianum* and *Pseudomonas fluorescens* produce antibiotics, siderophores, and hydrolytic enzymes that suppress pathogenic fungi and bacteria (Harman *et al*., 2004). Entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium anisopliae* infect and control insect pests, offering eco-friendly alternatives to chemical pesticides. Additionally, bacteriophages and viral biocontrols have been explored for targeted suppression of bacterial and insect pests, demonstrating the potential of microbiome-based biocontrol strategies in natural farming systems.

4. Advanced microbial technologies in organic and natural farming

The integration of cutting-edge microbial technologies has revolutionized the scope of organic and natural farming. High-throughput sequencing, metagenomics, and transcriptomics allow researchers to uncover the "hidden" diversity of soil microbes, including unculturable taxa that may possess novel functions (Shokralla *et al.,* 2012). Liquid microbial consortia formulations have emerged as promising alternatives to traditional carrier-based biofertilizers, offering improved stability, viability, and multi-strain compatibility.

Nanobiotechnology is being increasingly applied to microbial inoculants, where nano-carriers facilitate controlled release and enhanced delivery of microbial metabolites and nutrients. Synthetic biology and CRISPR- Cas based genome editing enable the design of tailor made microbial strains with enhanced functional traits, such as drought tolerance or high nutrient solubilization capacity (Liao *et al*., 2019). Moreover, microbial carbon farming leveraging soil microbes to enhance carbon sequestration is gaining traction as a strategy to combat climate change while improving soil health.

The application of artificial intelligence (AI) and precision agriculture tools further advances microbiome management. Machine learning algorithms can predict microbiome dynamics under different management regimes, enabling site-specific microbial interventions. Collectively, these technologies signify a paradigm shift from descriptive to predictive and prescriptive microbiome management, aligning organic and natural farming with modern scientific innovations.

5. Case studies and global success stories

Several successful models worldwide highlight the practical integration of soil microbiomes into organic and natural farming systems. In India, the Zero Budget Natural Farming (ZBNF) movement emphasizes the use of *Jeevamrutha* (a microbial-rich preparation) and other bio-inputs to promote soil fertility and plant health (Khadse *et al*., 2018). This approach has demonstrated enhanced crop resilience and reduced dependency on costly agrochemicals. In Sikkim, declared as India's first 100% organic state, the integration of microbial biofertilizers and biopesticides has been pivotal in sustaining crop productivity and environmental health.

In Europe, the widespread use of biocontrol agents such as *Trichoderma* and *Pseudomonas* has significantly reduced the reliance on synthetic pesticides, with strong policy backing from the European Union. Similarly, in Africa, the adoption of *Rhizobium* inoculants for legumes has shown remarkable improvements in yields, addressing food insecurity while maintaining soil fertility (Giller, 2001). These case studies collectively demonstrate that harnessing soil microbiomes is not merely a theoretical concept but a practical reality with global relevance.

6. Challenges and limitations

The integration of soil microbiomes into organic and natural farming systems offers transformative potential, but several challenges continue to restrict their widespread adoption.

i. Variability in field performance

One of the most pressing issues is the inconsistent performance of microbial inoculants in real-world conditions. While many strains perform successfully under laboratory and greenhouse settings, they often fail to deliver consistent results in farmers' fields due to variations in soil type, pH, moisture content, temperature, and interactions with indigenous microbes. This variability undermines farmers' confidence and slows adoption.

ii. Shelf-life and formulation constraints

Traditional carrier-based microbial inoculants are prone to rapid loss of viability during storage, transport, and application. This short shelf-life restricts the scalability of microbial products and results in uneven quality in the marketplace. Although liquid biofertilizers and nano-formulations are being developed, they remain relatively expensive and inaccessible to smallholder farmers.

iii. Knowledge gaps in soil microbial ecology

Despite significant advances in metagenomics and other omics technologies, a majority of soil microbes remain uncultured and functionally uncharacterized. This knowledge gap makes it difficult to design efficient microbial consortia that can be universally applied across agroecological zones. A more integrative approach combining ecological theory, systems biology, and field trials is necessary to close this gap.

4. Policy, regulation, and adoption barriers

The absence of standardized quality control and certification mechanisms for biofertilizers remains a global issue. Farmers often encounter poor-quality or contaminated products, which reduces trust in microbial solutions. Furthermore, adoption is slowed by inadequate extension services and the perception that microbial technologies deliver results more slowly than chemical inputs. Overcoming these barriers requires supportive policies, regulatory frameworks, and long-term farmer education (Pretty *et al.,* 2018).

7. Future Prospects

While challenges exist, the future of soil microbiome applications in organic and natural farming is highly promising, with several emerging directions offering transformative potential.

i. Microbiome engineering and designer consortia

Advances in systems biology and synthetic biology are enabling the development of customized microbial consortia targeted to specific crops, soils, and environments. Such "designer microbiomes" can overcome the limitations of single-strain inoculants by mimicking natural microbial communities and ensuring functional redundancy (Mueller and Sachs, 2015; Toju *et al*., 2018).

ii. The plant holobiont approach

Future sustainable agriculture will increasingly embrace the **holobiont concept**, where plants and their associated microbiota are treated as a single evolutionary and ecological unit. This approach acknowledges that plant fitness and productivity are deeply influenced by microbial partners, opening new avenues for breeding programs that select not only for plant traits but also for microbiome compatibility.

iii. Climate-resilient microbes

In the context of climate change, microbes that can enhance tolerance to abiotic stresses such as drought, salinity, and heat will play a pivotal role in ensuring food security. Identifying and deploying these stress-resilient microbes will be crucial for sustaining productivity under increasingly variable climates (Cavicchioli *et al*., 2019).

iv. Integration with digital agriculture

The future of organic and natural farming lies in precision management of soil microbiomes. Artificial intelligence (AI), machine learning, and big data analytics can model microbial interactions, predict inoculant performance, and recommend site-specific microbial applications, thereby reducing variability and enhancing success rates (Xu, Wang, Guo, Zhang, and Liu, 2022).

v. Circular bioeconomy and waste volorization

Microbial technologies will increasingly integrate into circular bioeconomy frameworks. By using microbial consortia to convert agricultural residues, food processing wastes, and other organic by-products into biofertilizers, biostimulants, and biopesticides, farming systems can reduce waste, improve soil fertility, and achieve sustainability.

These emerging directions demonstrate that soil microbiome science is not merely a tool for enhancing organic and natural farming but a cornerstone of **future-proof, climate-resilient, and circular agricultural systems**.

References

- Bender, S. F., Wagg, C., and van der Heijden, M. G. (2016). An underground revolution: Biodiversity and soil ecological engineering for agricultural sustainability. *Trends in Ecology and Evolution, 31*(6), 440-452. https://doi.org/10.1016/j.tree.2016.02.016
- Bulgarelli, D., Schlaeppi, K., Spaepen, S., Ver Loren van Themaat, E., and Schulze-Lefert, P.

(2013). Structure and functions of the bacterial microbiota of plants. *Annual Review of Plant Biology*, *64*(1), 807-838.

- Cavicchioli, R., Ripple, W. J., Timmis, K. N., Azam, F., Bakken, L. R., Baylis, M., and Webster, N. S. (2019). Scientists' warning to humanity: Microorganisms and climate change. *Nature Reviews Microbiology, 17*(9), 569-586.
- FAO. (2021). *The state of the world's land and water resources for food and agriculture: Systems at breaking point.* Food and Agriculture Organization of the United Nations.
- Fierer, N. (2017). Embracing the unknown: Disentangling the complexities of the soil microbiome. *Nature Reviews Microbiology, 15*(10), 579-590.
- Giller, K. E. (2001). Nitrogen fixation in tropical cropping systems (2nd ed.). Wallingford: CABI Publishing.
- Harman, G. E., Howell, C. R., Viterbo, A., Chet, I., and Lorito, M. (2004). Trichoderma species-Opportunistic, avirulent plant symbionts. *Nature Reviews Microbiology, 2*(1), 43-56.
- Khadse, A., Rosset, P. M., Morales, H., and Ferguson, B. G. (2018). Taking agroecology to scale: The zero budget natural farming peasant movement in Karnataka, India. *The Journal of Peasant Studies, 45*(1), 192-219.
- Liao, C., Ttofali, F., Slotkowski, R. A., Denny, S. R., Cecil, T. D., Leenay, R. T., and Beisel, C. L. (2019). Modular one-pot assembly of CRISPR arrays enables library generation and reveals factors influencing crRNA biogenesis. *Nature Communications, 10*(1), 2948.
- Mueller, U. G., and Sachs, J. L. (2015). Engineering microbiomes to improve plant and animal health. *Trends in Microbiology, 23*(10), 606-617.
- Pretty, J., Benton, T. G., Bharucha, Z. P., Dicks, L. V., Flora, C. B., Godfray, H. C. J., and Wratten, S. (2018). Global assessment of agricultural system redesign for sustainable intensification. *Nature Sustainability, 1*(8), 441-446.
- Reganold, J. P., and Wachter, J. M. (2016). Organic agriculture in the twenty-first century. *Nature Plants, 2*(2), 15221. https://doi.org/10.1038/nplants.2015.221
- Sharma, S. B., Sayyed, R. Z., Trivedi, M. H., and Gobi, T. A. (2013). Phosphate solubilizing microbes: Sustainable approach for managing phosphorus deficiency in agricultural soils. *SpringerPlus, 2*(1), 587.

- Shokralla, S., Spall, J. L., Gibson, J. F., and Hajibabaei, M. (2012). Next-generation sequencing technologies for environmental DNA research. *Molecular Ecology*, *21*(8), 1794-1805.
- Toju, H., Peay, K. G., Yamamichi, M., Narisawa, K., Hiruma, K., Naito, K. and Kiers, E. T. (2018). Core microbiomes for sustainable agroecosystems. *Nature Plants*, *4*(5), 247-257.
- Xu, Y., Wang, H., Guo, C., Zhang, Y., and Liu, X. (2022). Artificial intelligence in soil microbiome research: Current status and future perspectives. *Computational and Structural Biotechnology Journal*, *20*, 118-131.

ADVANCED FEEDING TECHNOLOGIES FOR COLD-WATER AQUACULTURE: MECHANISMS AND APPLICATIONS OF IMMERSIVE FEED SOAKERS AND SMART DELIVERY SYSTEMS IN RAINBOW TROUT (*Oncorhynchus mykiss*)

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Abstract

Cold-water aquaculture, particularly the farming of rainbow trout (*Oncorhynchus mykiss*), faces significant challenges due to reduced metabolic rates, impaired feed assimilation, and heightened stress sensitivity under low-temperature conditions. Traditional feeding methods often result in excessive nutrient leaching, poor feed conversion, and environmental degradation. Recent advances in feeding technologies including immersive feed soakers and sensor-driven smart delivery systems offer novel solutions to these challenges. Immersive feed soakers employ controlled hydration matrices that preserve feed integrity, enhance palatability, and enable temperature-responsive nutrient release, supporting digestive efficiency and sustained nutrient uptake. Smart delivery systems integrate real-time environmental and behavioral monitoring with adaptive algorithms to dynamically adjust feeding frequency, ration size, and nutrient composition, promoting precision nutrition and metabolic optimization. Combined with functional dietary components such as probiotics, prebiotics, and immunostimulants, these technologies improve stress resilience, immune function, and overall fish health. This chapter reviews the mechanisms, applications, and benefits of these advanced feeding strategies, highlighting their potential to enhance growth performance, resource efficiency, and environmental sustainability in cold-water rainbow trout aquaculture.

Key words: Cold-water aquaculture, Immersive Feed Soakers, Smart Delivery Systems, Rainbow Trout

1. Introduction

In recent years, the Internet of Things (IoT) and related technological advancements have revolutionized traditional agricultural practices, including aquaculture (A. Riansyah et al., 2020). Conventional fish farming methods are heavily dependent on manual labor, which increases production costs due to the need for constant supervision and management. Furthermore, with the aging workforce in agriculture worldwide, aquaculture faces significant challenges related to labor shortages. Addressing these constraints requires a paradigm shift toward automated and remotely managed operations. The deployment of IoT-enabled systems offers a solution by reducing labor requirements while enhancing productivity. These technologies are poised to play a pivotal role in improving monitoring processes and data analytics for aquaculture management (F. K. Došilović et al., 2018). By integrating a vast array of interconnected IoT devices, organizations can gather and process extensive datasets, enabling informed decision-making and operational efficiency (J. Waterman et al., 2020). Optimizing feeding strategies through technological interventions can yield substantial economic benefits by minimizing resource wastage and improving feed utilization efficiency (C. Zhou et al., 2018). With the rising demand for high-quality aquatic products, ensuring optimal fish health has become a top priority. Uneaten feed not only depletes oxygen levels but also contributes to the accumulation of harmful substances such as ammonia, thereby affecting fish welfare and growth performance (X. Yang et al., 2021; S. Zhao et al., 2019). Determining the precise nutritional needs of aquatic species remains complex, particularly when employing automated systems, which may struggle to adapt to the variable feeding requirements of fish in real time. To overcome these challenges, the integration of intelligent monitoring systems utilizing artificial intelligence (AI) frameworks is critical. These systems can predict feeding patterns, evaluate environmental parameters, and adapt feeding schedules to ensure optimal growth while safeguarding fish health. Cold-water aquaculture systems are becoming increasingly crucial for global food security, with rainbow trout (*Oncorhynchus mykiss*) among the most commercially important species. However, the low-temperature environments typical of such systems can impair digestive efficiency, suppress feeding behavior, and hinder metabolic processes. Traditional feeding methods often result in excessive nutrient wastage, water pollution, and stress-induced health complications. As the industry moves toward precision aquaculture, the adoption of advanced feeding technologies is indispensable for improving efficiency, promoting sustainable practices, and enhancing fish welfare in cold-water environments. Technological advances in feed processing have improved nutrient stability and feed acceptability and future research is expected to focus on species-specific nutritional programming, precision feeding to optimize health and growth of fishes (Parry et al, 2025). Recent innovations in larval weaning diets have emphasized the inclusion of functional ingredients such as probiotics, prebiotics, and immunostimulants, which support gut health, modulate immune responses, and enhance disease resistance during this vulnerable stage. Probiotics, including *Lactobacillus* and *Bacillus* species, improve gut microbiota balance, while prebiotics such as inulin and mannan oligosaccharides provide substrates for beneficial bacterial growth. Immunostimulants like ß-glucans and nucleotides further strengthen the larval immune system, leading to improved survival and robustness under hatchery conditions (Parry et al, 2025). These dietary strategies are highly relevant to advanced feeding technologies in cold-water aquaculture, particularly in rainbow trout

(*Oncorhynchus mykiss*), where mechanisms such as immersive feed soakers and smart delivery systems can optimize nutrient uptake. By integrating functional diets with sensor-driven or behavior-based feeding systems, feed can be precisely administered in alignment with larval appetite, metabolic activity, and environmental conditions, ensuring maximal assimilation of functional ingredients, reducing wastage, and enhancing overall growth, health, and resilience in aquaculture operations. This chapter focuses on the role of immersive feed soakers and sensor-driven smart delivery systems in mitigating stress and optimizing nutrient uptake in rainbow trout under cold-water farming conditions. It integrates engineering solutions with biological responses, emphasizing sustainability, animal welfare, and production efficiency.

2. Cold-Water Feeding Challenges in Rainbow Trout

Cold-water feeding in rainbow trout (*Oncorhynchus mykiss*) presents several challenges that affect growth, feed efficiency, and environmental sustainability. At low temperatures, metabolic rates decrease, leading to reduced appetite and impaired feed assimilation. Additionally, handling stress and temperature fluctuations can elevate cortisol levels, suppressing the immune system and increasing susceptibility to diseases. Traditional feed formulations often dissolve rapidly in cold water, resulting in nutrient leaching and poor feed conversion ratios. This excess feed contributes to nutrient runoff, accelerating eutrophication and harming aquatic ecosystems. Addressing these limitations requires innovative approaches that combine nutrient stabilization with feedback-controlled feeding systems. Recent advancements in aquaculture technology have led to the development of specialized feeds and feeding systems tailored for cold-water environments. For instance, BioMar's POWER H2O feed is designed for submerged feeding systems, offering enhanced physical properties that reduce pellet damage and nutrient loss in cold waters BioMar. Similarly, Innovasea's FlowFeeder delivers feed gently to fish below the surface, minimizing pellet damage and loss common with air-blown systems, thereby improving feed conversion ratios and reducing environmental impact Global Seafood Alliance. Furthermore, integrating Internet of Things (IoT) technologies with machine learning algorithms enables real-time monitoring and optimization of feeding practices. For example, an IoT-based environmental control system utilizes sensors to collect data on water temperature, pH levels, and fish behavior, allowing for dynamic adjustments to feeding schedules and environmental conditions. Similarly, precision aquaculture systems employ computer vision and IoT sensors to monitor fish size and count, determining optimal feed amounts and improving feeding efficiency. Incorporating these emerging technologies into cold-water trout farming can enhance feed efficiency, reduce environmental impact, and promote sustainable aquaculture practices.

3. Immersive Feed Soakers: Design, Mechanisms, and Benefits

3.1 Principles of Immersive Feed Soakers

Immersive feed soakers represent an innovative approach to nutrient delivery in cold-water aquaculture systems, particularly for species such as rainbow trout (*Oncorhynchus mykiss*) whose feeding efficiency is compromised under low and extremely higher temperature conditions. These devices employ controlled hydration matrices designed to reduce nutrient loss due to water-induced leaching, thereby preserving the structural and nutritional integrity of feed pellets. By encapsulating proteins, lipids, and micronutrients within a semi-permeable matrix, feed soakers enhance palatability and encourage voluntary feeding behavior even when metabolic rates are reduced. The functional design of these devices focuses on maintaining optimal feed texture and stability during immersion periods in cold water. This is achieved through the incorporation of hydrocolloids, polymers, or gelatinous materials that regulate water absorption and delay rapid dissolution. Such designs facilitate a controlled nutrient release profile, allowing sustained access to essential feed components while minimizing degradation.

3.2 Nutrient Release Kinetics

The controlled-release mechanism of immersive feed soakers depends on temperature-regulated diffusion processes. At low temperatures (5–15°C), water absorption into the matrix is slower, thereby extending the period over which nutrients remain available to the fish. The release kinetics are further influenced by the composition of the encapsulating material, feed particle size, and matrix density. Research into optimal formulations has demonstrated that a balance between hydration and nutrient retention can be achieved by modulating the ratio of binding agents and feed constituents. A second-order diffusion model may be applied to describe the release pattern:

$Qt = Q\infty\ (1-e-kt)$

Where:

Qt = amount of nutrient released at time t

$Q\infty$ = maximum releasable nutrient content

k = temperature-dependent rate constant

This is a second-order diffusion model describing how nutrients are gradually released from the feed matrix over time, with the release rate influenced by water temperature, feed composition, and matrix properties. The graph illustrates the kinetics of nutrient release (QtQ_tQt) from an immersive feed over time at three different temperatures: 5°C, 10°C, and 15°C. The x-axis represents time (hours), ranging from 0 to 50 hours, while the y-axis represents the cumulative amount of nutrient released, ranging from 0 to 100 units.

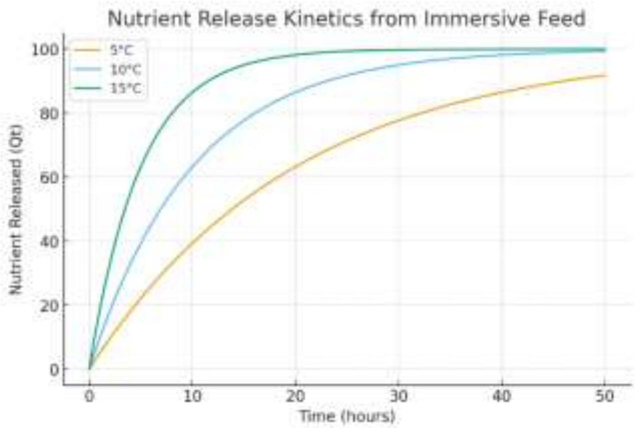

Figure 1 Graph showing nutrient release kinetics (QtQ_tQt) from immersive feed at different water temperatures. As expected, higher temperatures (e.g., 15°C) result in faster nutrient release, while lower temperatures (5°C) slow the process, extending nutrient availability.

Three distinct temperature-dependent release profiles are observed:

- **5°C (yellow curve):** Nutrient release is relatively slow. The release rate is initially rapid but gradually declines as it approaches an asymptotic value near 90 units by 50 hours, indicating incomplete release within the observed timeframe.
- **10°C (blue curve):** Nutrient release is faster than at 5°C, with the curve approaching nearly complete release (~100 units) by 50 hours. The initial release phase is steeper, showing an accelerated early nutrient diffusion.
- **15°C (green curve):** Nutrient release is the fastest at this temperature. The majority of the nutrients (~100 units) are released within approximately 20 hours, and the curve reaches a plateau early, indicating rapid attainment of maximum release.

Nutrient release from the feed exhibits a temperature-dependent diffusion process. Higher temperatures increase molecular mobility and solubility, thereby accelerating the nutrient release rate. The curves display a typical saturation behavior, where the initial release is rapid (driven by a high concentration gradient), followed by a slowing rate as the system approaches the maximum nutrient content. This trend aligns with diffusion-controlled release models, such as the Higuchi model (D.R. Paul 2011), where release rates decrease over time as the concentration gradient diminishes. Increasing temperature enhances the rate of nutrient release and reduces the time required to reach near-complete release. This behavior is critical in designing feed formulations for aquatic systems, as environmental temperature directly influences nutrient availability and bioavailability kinetics.

3.3 Interaction with Digestive Physiology

Nutrient release profiles directly influence gastrointestinal processing and metabolic assimilation in rainbow trout (G. Pascon et al, 2024). The gradual release of protein and lipid fractions supports enzyme-mediated digestion even when enzymatic activity is suppressed due to cold stress. Moreover, the preservation of feed texture stimulates feeding behavior, encouraging more consistent nutrient intake over extended periods. Controlled hydration also prevents premature disintegration, which otherwise leads to nutrient dilution and reduced feed conversion efficiency. The improved structural integrity ensures that feed reaches deeper into the digestive tract where absorptive surfaces are optimized for nutrient uptake. It is pertinent to mention that the technological advances in feed processing have improved nutrient stability and feed acceptability and future research is expected to focus on species-specific nutritional programming, precision feeding to optimize health and growth of fishes (Parry et al, 2025).

3.4 Environmental Impact

One of the critical advantages of immersive feed soakers lies in their potential to reduce nutrient runoff into surrounding aquatic ecosystems. Conventional feeding practices result in significant nutrient loss, particularly in low-temperature environments where feed remains suspended for prolonged periods. By limiting leaching and encouraging complete ingestion, feed soakers contribute to reduced accumulation of nitrogenous compounds and phosphates in water bodies, thereby mitigating eutrophication risks. Furthermore, nutrient conservation directly translates into lower feed input requirements, thereby decreasing the carbon footprint and environmental burden associated with feed production and transport.

4. Smart Delivery Systems: Automation and Real-Time Feeding Control

4.1 Types of Smart Feeders

Smart delivery systems in cold-water aquaculture integrate automated feeding mechanisms with real-time environmental and behavioral monitoring tools, optimizing feed administration according to the fluctuating metabolic rates of fish with changing temperatures. These systems ensure that feed is delivered efficiently, minimizing wastage and preventing stress-related disorders. Major categories of these systems include sensor-driven automated feeders, which adjust feeding schedules based on inputs from environmental sensors such as temperature, dissolved oxygen, or ammonia; behavior-based feeders, which use cameras or acoustic sensors to track fish swimming patterns, activity bursts, and appetite, triggering feeding responses aligned with natural foraging behavior; and data-integrated control systems, where feeding is modulated through algorithms that combine multiple sensor inputs to predict nutrient requirements and prevent overfeeding or underfeeding. Notably, the Division of Fish Nutrition and Biochemistry holds a design patent on such automated devices, highlighting their innovation in optimizing aquaculture nutrition management.

4.2 Key Parameters Monitored

In modern aquaculture systems, precise monitoring of multiple parameters is critical to optimize feeding efficiency and maintain fish health. Water quality indicators such as temperature are primary determinants of metabolic rate and enzymatic activity, enabling adjustment of feeding intensity in accordance with thermal fluctuations. Dissolved oxygen (DO) concentrations are essential for aerobic metabolism and nutrient assimilation, as hypoxic conditions can suppress feed intake and induce physiological stress. Temperature directly influences fish metabolism and physiology, affecting growth and productivity, while dissolved oxygen is essential for respiration and nutrient assimilation, with low levels causing stress and reduced feed intake (Durgesh et al, 2023). Ammonia and nitrite levels serve as indicators of protein catabolism and water quality, with elevated concentrations often reflecting overfeeding or insufficient water exchange, prompting automated corrections. Behavioral metrics provide additional real-time insight into fish welfare and appetite; for instance, swimming velocity and schooling patterns can indicate feeding motivation or environmental stress, while surface feeding behavior allows fine-tuning of ration delivery to match actual consumption. Feed residue monitoring using optical or imaging sensors ensures detection of uneaten particles, preventing nutrient wastage and minimizing water contamination. The integration of these parameters into automated control systems enables a responsive feeding strategy that maximizes nutrient utilization, supports growth performance, and maintains optimal culture conditions.

4.3 Feedback-Controlled Feeding Protocols

Smart feeders employ adaptive algorithms that integrate real-time sensor data into continuous feedback loops, allowing feeding protocols to respond dynamically to the physiological and behavioral needs of fish. By analyzing parameters such as water temperature, dissolved oxygen, and observed activity levels, these systems adjust both feeding frequency and ration size to match the fish’s metabolic requirements. This adaptive approach ensures that feed is delivered efficiently, enhancing feed conversion ratios while reducing waste and minimizing environmental stress. By continuously monitoring and responding to changing conditions, feedback-controlled feeding protocols optimize nutrient utilization, support fish welfare, and maintain stable culture environments in cold-water aquaculture.

4.4 Potential for Precision Nutrition

Beyond automating feed delivery, smart feeding systems offer the potential for precision nutrition by providing tailored dietary profiles that align with life-stage requirements and seasonal variations. Feed composition can be modulated according to growth phase, ensuring that fry, juveniles, and adults receive nutrients optimized for skeletal development, protein synthesis, and fat deposition.

During periods of thermal stress, handling, or disease outbreaks, these systems can deliver targeted antioxidant-rich or immunostimulatory supplements to mitigate physiological stress and enhance resilience. Additionally, feeding schedules can be synchronized with circadian rhythms to optimize digestive efficiency and nutrient assimilation. By integrating life-stage-specific formulations, environmental cues, and temporal feeding patterns, precision nutrition strategies maximize growth performance, feed efficiency, and overall fish health in cold-water aquaculture.

5. Influence on Stress Physiology and Immune Function

5.1. Key Biomarkers of Stress and Immune Modulation in Rainbow Trout

In rainbow trout, physiological responses to environmental and nutritional stressors can be quantitatively assessed using specific biomarkers, providing critical insights into how advanced feeding technologies modulate stress tolerance and immune capacity (Khansari AR et al, 2018) Elevated plasma cortisol levels indicate activation of the hypothalamic–pituitary–interrenal (HPI) axis, with prolonged secretion associated with muscle protein catabolism, reduced appetite, and impaired immune function. Heat shock proteins (HSP70, HSP90) are upregulated in response to thermal and oxidative stress, aiding in protein stabilization and cellular repair mechanisms. Antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx) constitute the primary defense against reactive oxygen species (ROS), with enhanced activity levels suggesting improved oxidative stress management facilitated by diet. Pro-inflammatory cytokines like interleukin-1 beta (IL-1β) and tumor necrosis factor-alpha (TNF-α) regulate the immune response to infection and injury, with balanced expression indicating effective immune activation without excessive inflammation. Lysozyme activity serves as a critical component of the innate immune system, providing defense against bacterial pathogens by lysing cell walls, reflecting immune readiness. Immunoglobulin M (IgM) represents the primary antibody involved in adaptive immunity, with elevated levels following nutritional interventions indicating improved immune memory and pathogen resistance.

5.2 Nutritional Modulation of Stress Responses

The integration of immersive feed soakers and smart delivery systems enables precise nutritional modulation of stress responses in rainbow trout by directly influencing key physiological biomarkers. Controlled nutrient release minimizes abrupt dietary fluctuations, thereby reducing metabolic stress and attenuating cortisol secretion. Diets enriched with stabilized lipid sources, vitamins C and E, and essential trace minerals enhance the activity of antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx), mitigating oxidative damage associated with temperature and environmental stress. Furthermore, the inclusion of prebiotics, probiotics, and bioactive peptides supports gut integrity and stimulates immune pathways, resulting in balanced pro-inflammatory cytokine profiles and elevated lysozyme activity. Sustained-release formulations providing prolonged access to essential fatty acids and micronutrients also strengthen adaptive immunity by promoting immunoglobulin M (IgM) production, thereby enhancing disease resistance during extended periods of stress and improving overall health and resilience in aquaculture systems.

6. Integration of Feed Technology with Environmental Monitoring

6.1. Smart Feeding and Environmental Monitoring in Precision Aquaculture

Advanced aquaculture systems integrate feed technology with environmental monitoring through a range of sensor platforms and data-driven algorithms to optimize feeding efficiency and fish health. Acoustic sensors, including hydrophones and sonar systems, detect movement patterns to identify feeding swarms or zones of inactivity within tanks or raceways, while optical sensors employing machine vision analyze particle size, density, and distribution of feed in the water column to estimate consumption rates. Continuous water chemistry monitoring of parameters such as dissolved oxygen, pH, ammonia, and nitrites enables real-time adjustments in feeding behavior. Emerging biometric sensors offer non-invasive assessments of physiological indicators, including respiration rate, heart rate, and skin mucus composition, allowing preemptive nutritional interventions. Complementing these technologies, data-driven feeding algorithms leverage artificial intelligence and machine learning to analyze historical and real-time datasets for predictive feeding. Pattern recognition models distinguish stress-related behaviors from normal activity, preventing unnecessary feeding during illness or low metabolic periods, while environmental anomaly detection triggers alerts in response to sudden drops in dissolved oxygen or temperature shifts, facilitating timely ration adjustments. Personalized feeding algorithms can be tailored to specific tank environments, accounting for water turnover rates, fish density, and seasonal variations, thereby enabling precise, adaptive feeding strategies that enhance growth, welfare, and resource efficiency.

6.2 Challenges in Implementation

The implementation of advanced feeding and environmental monitoring systems in aquaculture faces several technical and operational challenges. Sensor calibration and accuracy must be maintained despite biofouling, sedimentation, or electrical interference, which can compromise data reliability. False-positive detections, such as feeding triggers caused by non-relevant disturbances like mechanical vibrations, can lead to inefficiencies and feed wastage. Additionally, the cost-effectiveness of these systems must be carefully considered, balancing technological sophistication with the operational budgets of commercial aquaculture operations. Integration complexity also presents a significant challenge, as harmonizing diverse sensor types, software platforms, and hardware interfaces into a cohesive, responsive feeding system requires careful design and continuous management. Addressing these challenges is critical to ensure reliable, efficient, and economically viable precision feeding in modern aquaculture.

7. Research Frontiers and Future Directions

Future research on rainbow trout (*Oncorhynchus mykiss*) should focus on advancing the mechanisms and applications of immersive feed soakers and smart delivery systems to optimize nutrient utilization and stress management in cold-water aquaculture. Key directions include refining feed soaker matrices to achieve precise, temperature-responsive nutrient release that aligns with digestive enzyme activity and metabolic rhythms. Integration of functional ingredients such as probiotics, prebiotics, and immunostimulants within these systems can enhance gut health, immune modulation, and overall resilience. On the smart delivery side, developing AI-driven algorithms that combine behavioral monitoring, environmental sensing, and historical feeding data can enable real-time adjustments in ration size, timing, and nutrient composition. Research should also explore multi-sensor integration and predictive modeling to anticipate stress events and dynamically modulate feed. These innovations will enhance feed efficiency, reduce nutrient losses, and promote welfare-focused, sustainable production in cold-water trout farming.

8. Conclusion

Advanced feeding technologies, including immersive feed soakers and smart delivery systems, represent transformative innovations for cold-water aquaculture, particularly for rainbow trout (Oncorhynchus mykiss). By addressing the dual challenges of nutrient loss and stress-related physiological constraints, these technologies enhance feed stability, optimize nutrient bioavailability, and align feeding practices with environmental and behavioral cues. Immersive feed soakers reduce nutrient leaching, maintain pellet integrity, and enable controlled, temperature-responsive nutrient release, thereby supporting digestive efficiency and consistent nutrient uptake. Concurrently, sensor-integrated smart delivery systems leverage real-time behavioral and environmental data to dynamically modulate feeding frequency, ration size, and nutrient composition, promoting metabolic efficiency and reducing wastage. The integration of functional dietary components with precision feeding protocols further strengthens stress resilience, immune function, and overall fish health. Collectively, these innovations offer a sustainable, welfare-oriented framework for cold-water aquaculture, advancing growth performance, environmental stewardship, and resource-efficient production in rainbow trout farming.

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References

- A Riansyah, *et al.* Fish feeding automation and aquaponics monitoring system base on IoT 2020 6th International Conference on Wireless and Telematics (ICWT), IEEE (2020)
- C. Zhou, *et al.* Intelligent feeding control methods in aquaculture with an emphasis on fish: a review Rev. Aquacult., 10 (4) (2018), pp. 975-993
- D.R. Paul 2011 Elaborations on the Higuchi model for drug delivery International Journal of Pharmaceutics Volume 418, Issue 1, 10 October 2011, Pages 13-17 https://doi.org/10.1016/j.ijpharm.2010.10.037
- Durgesh Kumar Verma, Satyaveer Singh, Narendra Kumar Maurya, Parvind Kumar 2023, Important Water Quality Parameters in Aquaculture: An Overview Agriculture and environment Article ID: AEN-2022-03-06-007
- F.K. Došilović, M. Brčić, N. Hlupić Explainable Artificial Intelligence: A Survey. In 2018 41st International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO) IEEE (2018)
- G. Pascon, E. Daniso, G. Cardinaletti, M. Messina, F. Campagnolo, D. Zuccaccia, F. Tulli, Postprandial kinetics of digestive function in rainbow trout (Oncorhynchus mykiss): genes expression, enzymatic activity and blood biochemistry as a practical tool for nutritional studies, Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology, Volume 288, 2024, 111559, ISSN 1095-6433, https://doi.org/10.1016/j.cbpa.2023.111559.
- J. Waterman, H. Yang, F. Muheidat AWS IoT and the interconnected world–aging in place 2020 International Conference on Computational Science and Computational Intelligence (CSCI), IEEE (2020)
- Khansari AR, Balasch JC, Vallejos-Vidal E, Parra D, Reyes-López FE, Tort L. Comparative Immune- and Stress-Related Transcript Response Induced by Air Exposure and *Vibrio anguillarum* Bacterin in Rainbow Trout (*Oncorhynchus mykiss*) and Gilthead Seabream (*Sparus aurata*) Mucosal Surfaces. Front Immunol. 2018 May 2;9:856. doi: 10.3389/fimmu.2018.00856. PMID: 29770134; PMCID: PMC5940744.
- S. Zhao, *et al.* Adaptive neural fuzzy inference system for feeding decision-making of grass carp (Ctenopharyngodon idellus) in outdoor intensive culturing ponds Aquaculture, 498 (2019), pp. 28-36
- Umar Rasool Parry, Mir Ishfaq Nazir, and Oyas A. Asimi. 2025. "Advances in Weaning Strategies for Fishes: A Review of Recent Research and Developments". *Asian Journal of Advances in Research* 8 (1):210–218. https://doi.org/10.56557/ajoair/2025/v8i1520.
- X. Yang, *et al.* Deep learning for smart fish farming: applications, opportunities and challenges Rev. Aquacult., 13 (1) (2021), pp. 66-90.

STATUS OF INSECTICIDE RESISTANCE DEVELOPMENT IN MAJOR AGRICULTURE PESTS

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Abstract

Insecticide resistance poses a significant challenge to agricultural productivity worldwide, threatening food security and economic stability. This review article synthesizes current knowledge on the status of insecticide resistance development in major agricultural pests. It covers the primary mechanisms by which pests develop resistance, including metabolic resistance, target site mutations, and behavioural changes. Additionally, the review examines recent case studies across various crops and geographical regions, highlighting the pervasive nature of resistance issues. By providing a comprehensive overview of the current status of insecticide resistance, this article aims to inform researchers, policymakers, and practitioners about the complexities and critical areas requiring attention for sustainable pest management solutions.

Keywords: Insecticide, Resistance, Polyphagous, Management, Enzymes

Introduction

Insecticides are the chemicals used to control and manage different insect pests. It provides rapid control, is easily available and is cost-effective. Despite, all these benefits it also comes with major drawbacks such as resistance development. Insecticide resistance can be defined as an insect population that can no longer be controlled or managed by providing an insecticide dose that was previously used. Insecticides are mostly used in agriculture and household insect populations like gardens and other living spaces (Karaağaç, 2012). The Insecticide Resistance Action Committee (IRAC) is a technical group of CropLife International that mainly focuses on providing control or delaying resistance development (Nauen et al., 2019). The top 12 insect species with the maximum number of insecticide resistance cases include cotton bollworms, diamondback moths, sweet-potato whiteflies, cutworms, two-spotted spider mites and aphids (APRD, 2019). Insecticide resistance is mainly caused due to some kind of mutations in the DNA of insect pests. This mutation can take form in different forms and result in different kinds of mechanisms like target site resistance, metabolic resistance, behavioural resistance and physical resistance. The first case of insecticide resistance was reported in the San Jose scale against lime sulfur (Melander, 1915). In recent times total of 429 different insect species have been confirmed for developing insecticide resistance (Alyokhin et al., 2022) and 586 species resistant to one or more insecticides (APRD, 2019).

What causes insecticide resistance?

Insecticide resistance refers to a decrease in the susceptibility of a population of insects to the effects of an insecticide. This is evident in the consistent inability of an insecticide to achieve the anticipated level of insect control when applied under the recommendations on the product label, and when issues related to product storage, application, and atypical climatic or environmental conditions can be ruled out as potential causes for the failure. Insects can develop resistance to chemicals through several mechanisms, and it is common for pests to demonstrate multiple of these processes simultaneously.

1) **Behavioural resistance:** Resistant insects possess the ability to perceive and avoid toxins that pose a threat to them. This resistance mechanism has been observed in various types of insecticides, such as organochlorines, organophosphates, carbamates, and pyrethroids. In response to encountering specific insecticides, insects may cease feeding or relocate from the area where the insecticide was applied. For example, they may seek shelter on the underside of a sprayed leaf, move deeper into the crop canopy, or fly away from the targeted region.
2) **Penetration resistance**: Insects that are resistant to the poison may have a slower rate of absorption compared to insects that are susceptible to it. Penetration resistance occurs when the insect's exoskeleton creates obstacles that hinder the absorption of substances into their body. This can protect insects against a broad spectrum of insecticides. Penetration resistance often coexists with other types of resistance, and when penetration is reduced, it enhances the impact of those other mechanisms.
3) **Metabolic resistance**: Resistant insects may detoxify or destroy the poison more quickly than susceptible insects, or they may rapidly eliminate the hazardous substances from their bodies. Metabolic resistance is the most common mechanism and frequently poses the biggest obstacle. Insects utilise their internal enzyme systems to degrade pesticides. Resistant strains may have larger amounts or more effective forms of these enzymes. In addition to being more efficient, these enzyme systems may have a wide range of action (i.e., they may destroy a variety of pesticides).
4) **Altered target-site resistance:** A modification is made to the location in the insect where the toxic substance typically attaches to mitigate the effects of the insecticide. When it comes to resistance mechanisms, this is the second most prevalent one.

Resistance development is a major concern for farmers, researchers and companies and it requires lots of effort to manage resistance development in insect pests. For that, require data on the total number of insects with resistance chemicals. Therefore, this review article includes major insect species that developed resistance towards different chemicals in India.

Insecticide resistance in India:

1)American bollworm:

Helicoverpa armigera (Hubner) stands out as one of the most destructive pests affecting field crops. It is highly polyphagous with a wide geographical range and has great migratory potential (Fitt, 1989). These characteristics of *H. armigera* lead to the development of resistance against broad-spectrum insecticides such as synthetic pyrethroids, organophosphates, carbamates and cyclodienes (Chavan & Nimbalkar, 2004). Reddy (1988) reported the first case of resistance in *H. armigera* in Andhra Pradesh in 1987. Further various case studies were conducted. A high level of fenvalerate resistance was reported in Tamil Nadu (Pasupathy & Regupathy, 1994). Armes et al (1996) reported the highest level of resistance against cypermethrin and fenvalerate at 6500 and 3200-old respectively. It also identified the highest pyrethroid resistance in cotton and pulse cultivation areas in central and southern India. Population of *H. armigera* in Hyderabad escalating resistance against DDT and endosulfan in Jalna, Aurangabad and Prabhani from high to low (Regupathy et al., 1998). In further recent years, Kapoor *et al* (2000) reported resistance from Aurangabad, Prabhani and Jalna districts in chlorpyriphos, cypermethrin and endosulfan. Similarly, Kranthi *et al* (2002a) and Nimbalkar *et al* (2009) record the increasing resistance level towards cypermethrin with 8022 folds. Kranthi *et al* (200) also noticed the escalating level of resistance in endosulfan and cyclodine from Central India. *H. armigera* showed the maximum level of resistance towards synthetic pyrethroids including cypermethrin, fenvalerate, deltamethrin, lambda-cyhalothrin, and beta-cyfluthrin (Duraimurugan & Regupathy, 2005). During the 2005 cotton-growing region of Punjab state, insecticide resistance was systematically monitored and Gill and Dhawan (2006) found that the Mansa and Bathinda districts population showed resistance towards chlorpyriphos, endosulfan, Spinosad, cypermethrin and quinalphos. Predominant resistance was identified to quinalphos in Aurangabad and Prabhani districts by Nimbalkar *et al* (2009). Between 2005 to 2007, Bajya *et al* (2011) reported the highest level of resistance towards cypermethrin in the Sirsa, Hisar, Fatehabad, Jind and Bhiwani districts of Haryana. In the same region, *H. armigera* expressed a significant level of resistance towards another 4 insecticides endosulphan, quinalphos, methomyl and Spinosad used along with cypermethrin (Bajya et al., 2011). Another case of insecticide resistance was reported in the Raichur district of Karnataka towards pyrethroid, organophosphate and carbamate. Reports showed that the population of *H. armigera* is highly resistant to deltamethrin, monocrotophos and thiodicard (Ballari & Udikeri, 2021).

2) Pink bollworm:

In India, Pink bollworm (*Pectinophora gossypiella*) is a major problem for cotton-grown farmers, and the use of insecticides has been the primary management method. However, this led to the development of insecticide resistance in pink bollworms. Kranthi *et al* (2000) first reported the resistance in pink bollworms against pyrethroids in Bhatinda, Prabhani and Warangal. For the management of Pink bollworms in India Genetic Engineering Approval Committee (GEAC) approved Bt cotton-producing Cry 1Ac in 2002. Cotton cultivars were commercialized for cultivation and planted with 50000 ha in 2002 (Choudhary & Gaur, 2015). To delay the resistance development GEAC approved 20% of the planting of non-Bt cotton with Bt cotton (Mohan Komarlingam, 2018). Due to some factors including misunderstanding of the purpose of refuges and the desire to maximize short-term yield Indian farmers didn't grow non-Bt crops(Stone, 2004). The resistance of pink bollworm towards the cry1Ac was initially observed through laboratory bioassay conducted on offspring collected from the field in 2008 Gujrat (Dhurua & Gujar, 2011). In 2014, the damage percentage of pink bollworms on Bt cotton-producing Cry1Ac and Cry2Ac was 52 per cent higher than non-Bt crops in Central India (Naik et al., 2018). By end of the 2015 pink bollworm resistance was widespread all over India.

3) Diamondback moth:

The diamondback moth, *Pluttella xylostella* (L.) (Lepidoptera: Plutellidae), originates from the Mediterranean region (Huaripata & Sánchez, 2019). On cruciferous vegetables, the diamondback moth was first recorded in India in 1914 (Fletcher, 1914), which is now found to be a most destructive pest of the crops in various Indian states like Punjab, Haryana, Delhi, Uttar Pradesh, Bihar, Maharashtra, Tamil Nadu and Karnataka. DBM holds the second position in terms of resistance among insect species, displaying resilience to 91 different insecticides (Sparks et al., 1995). Additionally, it stands out as the initial species to manifest field resistance to *Bacillus thuringiensis* (Bt) Cry toxins. The *P. xylostella* exhibited resistance to the initial insecticides, DDT and parathion, as reported in Punjab (Verma & Sandhu, 1968). Subsequently, resistance to fenitrothion, malathion, and monocrotophos was observed in Punjab (Chawla & Kalra, 1976). In Karnataka, resistance to *P. xylostella* was found for Permethrin and fenvalerate (Krishnakumar et al., 1986). Haryana reported resistance to Cypermethrin and fenvalerate (Saxena et al., 1989), while Punjab, Uttar Pradesh, and Delhi showed resistance to deltamethrin and quinalphos (Chawla & Joia, 1992). In Tamil Nadu, *B. thuringiensis* (Bt) was discovered to be resistant to *P. xylostella* (Rabindra et al., 1995). Uttar Pradesh reported resistance to Cypermethrin and fenvalerate (Raju & Singh, 1995), and Tamil Nadu observed resistance to Endosulphan, quinalphos, Monocrotophos, and fenvalerate (Renuka & Regupathy, 1996). Karnataka reported resistance to endosulphan, chlorpyriphos, methyparathion, quinalphos, methomyl, monocrotophos, carbaryl, alphamethrin, fenvalerate, cypermethrin, deltamethrin, cartap hydrochloride, and Bt (Sannaveerappanavar, 1995). Additionally, Harayana noted resistance to Monocrotophos, malathion, endosulfan, and dichlorvos (Kalra et al., 1997). Ramya et al (2016) investigate the filed population of *P. xylostella* to insecticide resistance by using the leaf dip bioassay method. The motive for investigation was to evaluate the resistance levels to various insecticides including acephate, chlorpyriphos, cypermethrin, indoxacarb, Spinosad and novaluron. Results indicated that the population showed moderate to high-level resistance, particularly against chlorpyriphos, cypermethrin and acephate (Ramya et al., 2016). Increasing the rate of insecticide resistance development from F1 to F3 generation towards acephate, cypermethrin, cartap hydrochloride and Cry2Ab toxin (Sunitha et al., 2020). In Tamil Nadu, India insecticide resistance status was checked and revealed that a low to moderate level of resistance was observed against Spinosad, emamectin benzoate and indoxacarb. Conversely, elevated levels of resistance were observed against chlorantraniliprole, flubendaimide, fipronil and cypermethrin in all field populations (Tamilselvan et al., 2021).

4) Cutworm:

Spodoptera litura (F.) commonly known as the tobacco cutworm, is a species of noctuid moth that is found throughout the tropical and subtropical regions of Asia, Africa, and Australia. It is a major pest of many crops, including tobacco, cotton, soybean, tomato, and vegetables. The tobacco caterpillar, *S. litura* showed resistance to several chemicals such as cypermethrin, fenvalerate, endosulfan, quinalphos, monocrotophos and methomyl. Major chemicals resistant due to detoxification of enzymes by microsomal P450-dependent monooxygenases. Pre-treatment with piperonyl butoxide, resulted from complete suppression of cypermethrin resistance (Armes et al., 1997). Kumar and Regupathy reported the highest level of resistance to fenvalerate in the field population of Coimbatore, Usilampatti and Palani regions of Tamil Nadu (N. Kumar & Regupathy, 2001). *S. litura* expressed the highest level of resistance against cypermethrin insecticides in all the strains collected from South India (Kranthi et al., 2002). *S. litura* from Punjab, India showed 46.6-70% survival with the tropical application of discriminating dose profenophos and chlorpyriphos (Kaur et al., 2006). Monitoring of insecticide resistance in a field population of *S. litura* from seven different locations of Maharashtra and results showed that the resistance ratio changes for chlorpyrifos was 3 to 88 fold, for quinalphos resistance ratio was changed from 3 to 63 fold and for lamba-cyhalothrin values changed from 2 to 42 fold (Gandhi et al., 2016). *S. litura* larvae with the presence of gut bacteria showed resistance to chemicals while in the absence of gut bacteria more susceptible towards flubendiamide, indoxacarb and chlorpyriphos (Gadad et al., 2016). Monitoring of insecticide resistance in the field population of Kerala state from three different regions expressed maximum resistance towards chorpyriphos, quinalphos, lambda cyhalothrin and cypermethrin (Sreelakshmi et al., 2017). *S. litura* from Kumaon Himalaya, in soybean showed resistance to indoxacarb 14.5% SC, chlorantraniliprole 18.5% SC, fipronil 5% SC, chlorpyriphos 50% +cypermethrin 5% EC and profenophos 40% + cypermethrin 4% EC (Joshi et al., 2023b). Mainly resistance developed in *S. litura* in all regions due to higher activity of detoxification enzymes (Joshi et al., 2023a).

5) Leaf Hopper:

Leafhopper nymphs and adults suck the sap from leaves and inject toxic saliva into tissues causing phytotoxic symptoms known as hopper burn. As the infestation increases, the affected leaves turn pale at the margins first and then result in crinkling, curling, reddening and browning of leaves leading to complete desiccation of plants (Balakrishnan et al., 2007). Besides cotton, it attacks important crops like okra (*Abelmoschus esculentus* L.), brinjal (*Solanum melongena* L.), potato (*Solanum tuberosum* L.) and castor (*Ricinus communis* L.). Chemical insecticides are heavily used for the management of this insect and a major problem regarding this is the development of resistance in leafhoppers against insecticides. This pest has developed resistance to conventional insecticides like endosulfan, monocrotophos and cypermethrin. Initially, a new group of chemicals neonicotinoids viz., imidacloprid, thiamethoxam and acetamiprid were found to be more toxic than conventional insecticides like malathion and dimethoate (Kalra et al., 2001). Karla et al in 2001 reported that Insecticides are proving ineffective against the adults of *A. biguttula biguttula* on okra at Hisar. LC50 value (%) of monocrotophos is 0.063, dimethoate 0.178, indicating the development of resistance in leafhoppers to the commonly recommended insecticides. Chaudhari et al., (2015) reported very high resistance ratios such as 108.68, 78.24 and 25.96 fold for imidacloprid, thiamethoxam and acetamiprid, respectively when compared to 29.04 and 9.29 folds for monocrotophos and acephate, respectively from Surat (Chaudhari et al., 2015). In Karnataka, leafhoppers developed more resistance towards imidacloprid and lowest in dinotefuran among different generation neonicotinoids such as thiamethoxam, acetamiprid, thiacloprid and clothianidin due to increasing in activity of detoxifying enzymes (glutathione-S-transferase)(Halappa & Patil, 2016). Detoxifying enzymes play a significant role in developing insecticide resistance in most insects. Telangana state monitored insecticide resistance levels in the field population of *N. lugens* and observed that buprofezin 25 SC showed the highest level of resistance followed by neonicotinoids such as imidacloprid 17.8 SL. In addition, a significant level of resistance was observed against thiamethoxam 25 SG and galmour 80 WG (ethiprole 40% + imidacloprid 40% WG). The field population of rice leafhoppers was also susceptible to dinotefuran 20 SG and organophosphate compounds such as monocrotophos 36 SL, dichlorvos 76 EC, chlorpyriphos 20 EC and acephate 75 WP (Mohan et al., 2019). The bioassay study carried out on the cotton leaf hopper *Amrasca devastans* (Dist.) found that the leafhopper developed slight resistance to neonicotinoids such as imidacloprid 17.8 SL, acetamiprid 20 SP and thiamethoxam 25WG when compared to organophosphate insecticides such as acephate 75 SP and monocrotophos 36 SL (Mahalakshmi & Prasad, 2020). The field population of rice brown plant hopper of Godavari district of Andhra Pradesh state, India showed maximum resistance towards imidacloprid and thiamethoxam but there was no resistance against dinotefuran which is the opposite of all previous case studies. Moderate to higher levels of resistance to ethiprole and glmore 80 WG (B. N. Reddy et al., 2022). In Punjab rice brown planthopper (*Nilaparvata lugens*) developed resistance towards all test locations including Ludhiana, Patiala and Kapurthala. Less resistance ratio was observed towards buprofezin from the Ludhiana population, while Patiala and Kapurthala populations showed the least resistance to quinalphos (Deosi & Suri, 2022). In this case, resistance is also due to the higher activity of detoxifying enzymes such as esterases in the field-collected Ludhiana population while acetylcholinesterase in the Ludhiana and Patiala populations.

6) Aphids:

Aphids are considered to be a serious pest to almost all crops and alternative host plants because of their polyphagous feeding habits. *Aphis nerrii* and *Aphis fabae* damaged the beautiful ornamental plants whereas *Aphis brassicae* and *Myzus persicae* damaged the vegetables mainly cabbage. To prevent yield loss farmers mainly depend on chemical control methods. Indiscriminate use of chemicals caused pest resistance. The aphid can become resistant to many pesticides which is a growing concern due to its adverse environmental impacts. Cotton aphid *Aphis gossypii* (Glover) from Guntur district, Andhra Pradesh showed resistance towards all recommended insecticides such as endosulfan, monocrotophos, dimethoate, acephate and cypermethrin (Chalam et al., 2003). Cabbage aphid *Brevicoryne brassicae* expressed resistance to imidacloprid, acetamiprid, dimethoate and thiamethoxam was 137.80, 85.06, 44.17 and 13.50 folds, respectively (Nale et al., 2016). Field population of *Aphis gossypii* from Yavatmal, Amravati, Wardha and Buldhana districts of Vidarbha (MS) assayed for insecticide resistance by leaf dip method and found that acetamiprid, methyl demeton and dimethoate were very least toxic to Yavatmal and Amravati population while Buldhana population seems to resistance against all insecticides (Kulkarni et al., 2017). Cotton aphid *A. gossypii* from Tamilnadu found out that the aphid population expressed maximum resistance against all neonicotinoids including acetamiprid, imidacloprid, thiamethoxam and thiacloprid but very least or no resistance was showed against clothianidin in addition, dinotefuran and thiamethoxam was found out that showed maximum resistance to all six locations (Bose et al., 2020). In Punjab, a laboratory experiment was carried out to know the development of resistance in *Lipaphis erysimi* (Kalt.) which showed maximum resistance for dimethoate 30EC while a very low level of resistance was found against thiamethoxam 25WG (M. Singh et al., 2021).

7) Thrips:

Tiny insects with fringed wings penetrate the epidermal layer of green plants and suck out their cell contents, discolouring and silvering the leaves. The insect order Thysanoptera includes thrips. In warm regions, thrips show maximum reproduction and short life cycles with the only management practice being pesticide application. However, thrips can easily develop resistance to insecticides. The field population of *Thrips tabaci* Lindeman from Kumbakonam in Tamilnadu started to develop resistance against imidacloprid, thiamethoxam and dimethoate (Praveen & Regupathy, 2003). Guntur district, Andhra Pradesh population of chilli thrips, *Scirtothrips dorsalis* showed resistance to different chemicals such as monocrotophos, acephate, phosalone, dimethoate, carbaryl and triazophos with 4.19, 6.80, 5.59, 4.06 and 3.39 fold respectively (Vanisree et al., 2011). *Scirtothrips dorsalis* population in citrus-grown regions of Maharashtra developed 21 and 28-fold resistance against spinosad in 2016 and 2017, respectively due to the continuous application of a single insecticide over a long period (Rao et al., 2019).

8) Whiteflies:

Whiteflies are sap suckers under the family Aleyrodidae and order Hemiptera. Both adults and immature stages of whiteflies suck sap from the plants and reduce their vigour, causing yellowing and premature leaf fall. Besides, they secrete a large amount of honeydew triggering the development of black sooty mould which hinders photosynthesis. They also transmit different types of plant pathogenic viruses (Taquet et al., 2020). The high number of generations per year, availability of alternate hosts, presence of wax and abaxial surface habitat of whiteflies make them difficult to manage effectively (Pym et al., 2019). These characteristics triggered the indiscriminate use of insecticides in the farmers' fields to control whiteflies, which in turn resulted in the development of a high level of insecticide resistance (Horowitz & Ishaaya, 2014). Cotton whitefly collected from different parts of Andhra Pradesh (India) showed 5.40-fold resistance to endosulfan and 7.2-fold resistance to BHC (Prasad et al., 1993). *Bemisia tabaci* is reported to develop resistance to a wide class of insecticides including organophosphates, carbamates, pyrethroids, chlorinated hydrocarbons, insect growth regulators and several insecticides with novel modes of action (Elbert & Nauen, 2000; D. Singh et al., 2001). Singh et al (2001a) observed a low level (4.6 to 20 fold) of resistance to endosulfan in *B. tabaci* bioassayed from different regions of Punjab State (India). On the contrary, Kranthi et al (2002) observed negligible resistance to cyclodiene endosulfan in *B. tabaci* strains collected from central and southern India. Later studies revealed high resistance levels against endosulfan in populations from North India compared to South India (Sethi & Dilawari, 2008). Whitefly populations from seven different locations displayed widespread resistance to imidacloprid with the highest in Bathinda (North India) and the lowest in Coimbatore (South India) (Sethi and Dilawari 2008). The population of whiteflies from different regions of Punjab was resistant towards chemicals such as triazophos, ethion, spiromesifen and diafenthiuron. Whiteflies from Fazika expressed maximum resistance to spiromesifen followed by triazophos, while the Mansa population showed significant resistance against triazophos and the Ludhiana population showed maximum resistance to triazophos followed by diafenthiuron (V. Kumar & Grewal, 2018). In vegetable production for the management of whiteflies, only insecticide spray proved as effective management. Resistance ratio was observed for acephate, triazophos, indoxacarb, dinotefuran, tolfenpyrad, spiromesifen, pyriproxyfen and flonicamid were 131.48, 83.67, 2.51, 34.52, 27.56, 31.89, 30.08 and 45.92 folds, respectively (Roy et al., 2019).

Conclusion:

The development of insecticide resistance in major agricultural pests is a multifaceted problem that demands urgent and coordinated action. Our review highlights the extensive spread of resistance across different pest species and agricultural settings, driven by factors such as over-reliance on chemical controls and insufficient implementation of integrated pest management practices. Understanding the mechanisms of resistance, including genetic, biochemical, and behavioural adaptations, is crucial for developing effective countermeasures. Moving forward, it is essential to adopt a holistic approach that combines chemical, biological, and cultural strategies to manage pest populations sustainably. Emphasis should be placed on regular resistance monitoring, fostering the development and use of biopesticides, and educating stakeholders about best practices in pest management. Policymakers must also play a pivotal role by supporting research and facilitating the adoption of innovative solutions. Ultimately, addressing the challenge of insecticide resistance will require collaborative efforts from researchers, farmers, industry stakeholders, and regulatory bodies. By working together, it is possible to develop and implement strategies that not only curb the spread of resistance but also promote the long-term health and productivity of agricultural ecosystems.

References:

[1]Alyokhin A, Chen Y H, Udalov M, Benkovskaya G, Lindström L. Evolutionary considerations in potato pest management. In *Insect Pests of Potato*: Elsevier;2022. pp. 429–450.

[2]APRD. *Arthropod pesticide resistance database*.2019.

[3]Armes N J, Jadhav D R, DeSouza K R. A survey of insecticide resistance in *Helicoverpa armigera* in the Indian subcontinent. Bulletin of Entomological Research. 1996; **86**(5): 499–514.

[4]Armes N J, Wightman J A, Jadhav D R, Ranga Rao G V. Status of insecticide resistance in *Spodoptera litura* in Andhra Pradesh, India. Pesticide Science. 1997; **50**(3): 240–248.

[5]Bajya D R, Monga D, Kumhar K C, Tyagi M P, Suby S B. Monitoring of insecticide resistance in American bollworm (*Helicoverpa armigera,* Hubner) in cotton belts of Haryana. Journal of Cotton Research and Development. 2011; **25**(2): 269–272.

[6]Balakrishnan N, Murugesan N, Vanniarajan C, Ramalingam A, Suriachandraselvan M. Screening of cotton genotypes for resistance to leafhopper, *Amrasca biguttula biguttula* Ishida in Tamil Nadu. 2007.

[7]Ballari H S, Udikeri S S. Persisting Resistance of *Helicoverpa armigera* (Lepidoptera: Noctuidae)

to Pyrethroid, Organophosphate and Carbamate Insecticides. Artic. Pakistan J. Zool. 2021.

[8]Bose A, Murugan M, Shanthi M, Ramalingam J, Mini M L. Prevalence of neonicotinoid resistance in cotton aphid *Aphis gossypii* (Glover). Indian Journal of Entomology. 2020; **82**(1): 110–114.

[9]Chalam M S V, Rao G, Chinnabbai C. Insecticide resistance and its management in cotton aphid, *Aphis gossypii* Glover in Guntur District, Andhra Pradesh. Annals of Plant Protection Sciences. 2003; **11**(2): 228–231.

[10]Chaudhari V K, Desai H R, Patel N M. Assessment of the insecticide resistance builds up on cotton leaf hopper, *Amarasca biguttula* (Ishida). Int. J. Adv. Multidiscip. Res. 2015; **2**: 4–8.

[11]Chavan V M, Nimbalkar S A. Seasonal monitoring of insecticide resistance in *Helicoverpa armigera* (Hubner). 2004.

[12]Chawla R P, Joia B S. Studies on the development of resistance in the diamond back moth, *Plutella xylostella* (L.) to quinalphos in Punjab.1992.

[13]Chawla R P, Kalra R L. Studies on insecticide resistance in *Plutella xylostella* Linn.(Diamondback moth). Indian J. Plant. Prot. 1976; **4**:170–179.

[14]Choudhary B, Gaur K. Biotech cotton in India, 2002 to 2014. ISAAA Series of Biotech Crop Profiles. ISAAA: Ithaca, NY. 2015. 1–34.

[15]Deosi K K, Suri K S. Status of insecticide resistance in rice brown planthopper (*Nilaparvata lugens*) in Punjab. Indian Journal of Agricultural Sciences. 2022; **92**(2): 203–207.

[16]Dhurua S, Gujar G T. Field-evolved resistance to Bt toxin Cry1Ac in the pink bollworm, *Pectinophora gossypiella* (Saunders)(Lepidoptera: Gelechiidae), from India. Pest Management Science. 2011;**67**(8): 898–903.

[17]Duraimurugan P, Regupathy A. Synthetic pyrethroid resistance in field strains of *Helicoverpa armigera* (Hubner)(Lepidoptera: Noctuidae) in Tamil Nadu, South India. American Journal of Applied Sciences. 2005;**2**(7): 1146–1149.

[18]Elbert A., Nauen R. Resistance of *Bemisia tabaci* (Homoptera: Aleyrodidae) to insecticides in southern Spain with special reference to neonicotinoids. Pest Management Science: Formerly Pesticide Science. 2000;**56**(1): 60–64.

[19]Fitt G P. The ecology of *Heliothis* species in relation to agroecosystems. Annual Review of Entomology. 1989;**34**(1): 17–53.

[20]Fletcher T B. Some South Indian Insects and Other Animals of Importance: Considered Especially from an Economic Point of View/by T. Bainbrigge Fletcher. Bishen Singh Mahendra Pal Singh. 1914.

[21]Gadad H, Vastrad A S, Krishnaraj P. Gut bacteria mediated insecticide resistance in *Spodoptera litura* (Fab.). Journal of Experimental Zoology India. 2016; **19**(2): 1099–1102.

[22]Gandhi K, Patil R H, Srujana Y. Field resistance of *Spodoptera litura* (Fab.) to conventional

insecticides in India. Crop Protection. 2016;**88**: 103–108.

[23]Gill H K., Dhawan A K. Monitoring of insecticide resistance to *Helicoverpa armigera* (Hubner) in cotton growing areas of Punjab. Pesticide Research Journal. 2006;**18**(2): 150–153.

[24]Halappa B, Patil R K. Detoxifying enzyme studies on cotton leafhopper, *Amrasca biguttula biguttula* (Ishida), resistance to neonicotinoid insecticides in field populations in Karnataka, India. Journal of Plant Protection Research. 2016;**56**(4).

[25]Horowitz A R, Ishaaya I. Dynamics of biotypes B and Q of the whitefly *Bemisia tabaci* and its impact on insecticide resistance. Pest Management Science. 2014; **70**(10):1568–1572.

[26]Huaripata C, Sánchez G. Life Cycle of the Diamondback Moth *Plutella xylostella* L.(Lepidoptera: Plutelli-dae), in Broccoli and Cauliflower under Laboratory Conditions. Peruvian Journal of Agronomy. 2019;**3**(1): 1–5.

[27]Joshi R, Gaur N, Mathpal S. Biochemical Mechanism of Insecticide Resistance in *Spodoptera litura* (F) Populations from Uttarakhand. Indian Journal of Entomology. 2023a: 892–897.

[28]Joshi R, Gaur N, Mathpal S. Insecticide resistance development and detoxification enzyme activities of *Spodoptera litura* (Fabricius) in soybean from Kumaon Himalayas. Legume Research-An International Journal. 2023b;**46**(7):927–933.

[29]Kalra V K, Sharma S S, Chauhan R, Bhanot J P. Shift in the level of resistance together with relative toxicity of some commonly used and important insecticides to diamond back moth, *Plutella xylostella* (L.) in Haryana (India). Journal of Entomological Research. 1997;**21**(4): 351–354.

[30]Kalra V K, Singh R, Saini R K, Rohilla H R, Jaglan R S, Chauhan R, Sharma S S. Occurrence of insecticide resistance in leafhopper, *Amrasca biguttula biguttula* (Ishida) on Okra. Journal of Entomological Research. 2001;**25**(4): 263–265.

[31]Kapoor S K, Sohi A S, Singh J, Russell D, Kalra R L. Insecticide Resistance in *Helicoverpa armigera* (Hiibner) in Punjab, India. Pesticide Research Journal. 2000; **12**(1): 30–35.

[32]Karaağaç S U. *Insecticide resistance*. IntechOpen London, UK. 2012.

[33]Kaur A, Kang B K, Singh. Monitoring of insecticide resistance in *Spodoptera litura* (Fabricius) in Punjab, India. Pesticide Research Journal. 2006;**18**(1): 51–53.

[34]Kranthi K R, Jadhav D R, Kranthi S, Wanjari R R, Ali S S, Russell D A. Insecticide resistance in five major insect pests of cotton in India. Crop Protection. 2002a;**21**(6): 449–460.

[35]Kranthi K R, Jadhav D R, Kranthi S, Wanjari R R, Ali S S, Russell D A. (2002b). Insecticide resistance in five major insect pests of cotton in India. Crop Protection. 2002b;**21**(6): 449–460.

[36]Krishnakumar N K, Srinivasan K, Suman C L, Ramachander P R. Optimum control strategy of cabbage pests from a chemical control trial. 1986.

[37]Kulkarni U S, Khandar R S, Madankar S S. Monitoring of resistance to conventional insecticides

in field populations of *Aphis gossypii* Glover from major cotton growing areas of Vidarbha. International Journal of Chemical Studies. 2017; **5**(6): 1136–1139.
[38]Kumar N, Regupathy A. Status of insecticide resistance in tobacco caterpillar *Spodoptera litura* (Fabricius) in Tamil Nadu. Pesticide Research Journal. 2001;**13**(1): 86–89.
[39]Kumar V, Grewal G K. Insecticide resistance in whitefly, *Bemisia tabaci* (Gennadius) on Cotton in Punjab. Journal of Entomological Research. 2018;**42**(1): 75–80.
[40]MahaLakshmi M S, Prasad N V V S D. Insecticide Resistance in Field Population of Cotton Leaf Hopper, *Amrasca devastans* (Dist.) in Guntur, Andhra Pradesh, India. International Journal of Current Microbiology and Applied Sciences. 2020;**9**(6):3006–3011. https://doi.org/10.20546/ijcmas.2020.906.361
[41]Melander A L. Varying susceptibility of the San Jose scale to sprays. Journal of Economic Entomology. 1915;**8**(5): 475–481.
[42]Mohan Komarlingam S. Refuge-in-bag for Bt cotton. Current Science. 2018;**114**(4): 726.
[43]Mohan U, Lakshmi V J, Sharma S, Katti G R, Chirutkar P M, Krishnaiah N V. Monitoring of insecticide resistance in Rice brown planthopper *Nilaparvata lugens* (Stål) in Nalgonda District of Telangana State, India. Annals of Plant Protection Sciences. 2019;**27**(2): 172–176.
[44]Naik V C, Kumbhare S, Kranthi S, Satija U, Kranthi K R. Field-evolved resistance of pink bollworm, *Pectinophora gossypiella* (Saunders)(Lepidoptera: Gelechiidae), to transgenic *Bacillus thuringiensis* (Bt) cotton expressing crystal 1Ac (Cry1Ac) and Cry2Ab in India. Pest Management Science. 2018;**74**(11):2544–2554.
[45]Nale D A, Bhede B V, Bharati M S. Insecticide resistance in cabbage aphid *Brevicoryne brassicae*. Journal of Entomological Research. 2016;**40**(2): 187–189.
[46]Nauen R, Slater R, Sparks T C, Elbert A, Mccaffery A. IRAC: insecticide resistance and mode-of-action classification of insecticides. Modern Crop Protection Compounds.2019;**3**:995–1012.
[47]Nimbalkar R K, Shinde S S, Tawar D S, Muley S P. Response of cotton bollworm *Helicoverpa armigera* (Hubner)(Lepidoptera: Noctuidae) to different insecticides in Maharashtra, India. World Journal of Agricultural Sciences. 2009;**5**(2): 250–255.
[48]Pasupathy S, Regupathy A. Status of insecticide resistance in the American bollworm *Helicoverpa armigera* Hubner in Tamil Nadu. Pesticide Research Journal. 1994;**6**(2):117–120.
[49]Prasad V D, Bharati M, Reddy G P V. Relative resistance to conventional insecticides in three populations of cotton whitefly, *Bemisia tabaci* (Gennadius) in Andhra Pradesh. 1993.
[50]Praveen P M, Regupathy A. Insecticide Resistance in Field Populations of Cotton Thrips (*Thrips tabaci* Lindeman) in Major Cotton Growing Regions of Tamil Nadu. Pesticide Research Journal. 2003;**15**(2):197–200.

[51]Pym A, Singh K S, Nordgren Å, Davies T E, Zimmer C T, Elias J, Slater R, Bass C. Host plant adaptation in the polyphagous whitefly, *Trialeurodes vaporariorum*, is associated with transcriptional plasticity and altered sensitivity to insecticides. BMC Genomics. 2019;**20**:1–19.

[52]Rabindra R J, Gailce Leo Justin C, Jayaraj S. Relative susceptibility of two larval populations of diamond-back moth (*Plutella xylostella*) to insecticides and *Bacillus thuringiensis*. Indian Journal of Agricultural Science. 1995;**65**:152–152.

[53]Raju S V S, Singh H N. Resistance levels in the field population of *Plutella xylostella* (L.) to certain commonly used insecticides. 1995.

[54]Ramya S L, Venkatesan T, Murthy K S, Jalali S K, Abraham V. Field-evolved insecticide resistance and biochemical validation of enzyme activities in diamondback moth, Plutella xylostella. Indian J Plant Protec. 2016; **44**:9–15.

[55]Rao C N, George A, Rahangadale S. Monitoring of resistance in field populations of *Scirtothrips dorsalis* (Thysanoptera: Thripidae) and *Diaphorina citri* (Hemiptera: Liviidae) to commonly used insecticides in citrus in Central India. Journal of Economic Entomology. 2019;**112**(1):324–328.

[56]Reddy A S. *Heliothis armigera* (Hubner)–a serious threat to cotton cultivation in India. National Workshop on Heliothis Management. Tamil Nadu Agriculture University, Coimbatore, India. 1988:249–262.

[57]Reddy B N, Lakshmi V J, Umamaheswari T. Insecticide resistance monitoring in the field populations of brown planthopper, *Nilaparvata lugens* (Stål) in Andhra Pradesh, India. Journal of Experimental Zoology India. 2022;**25**(2).

[58]Regupathy A, Jadhav D, Kapoor S K, Singh D, Kranthi K, Russel D. Patterns of insecticide cross resistance in *Helicoverpa armigera* and *Bemisia tabaci* in India. Newfrontiers in Cotton Research: World Cotton Res. Conf. 1988;**2**:6–12.

[59]Renuka S, Regupathy A. Monitoring of insecticide resistance in diamondback moth *Plutella xylostella* (Linnaeus) in Tamil Nadu. Pesticide Research Journal. 1996;**8**(2):168–171.

[60]Roy D, Bhattacharjee T, Biswas A, Ghosh A, Sarkar S, Mondal D, Sarkar P K. Resistance monitoring for conventional and new chemistry insecticides on *Bemisia tabaci* genetic group Asia-I in major vegetable crops from India. Phytoparasitica. 2019;**47**:55–66.

[61]Sannaveerappanavar V T. Studies on insecticide resistance in the diamondback moth, *Plutella xylostella* (L)(Lepidoptera: Yponomeutidae) and strategies for its management. Ph. D. Thesis University of Agricultural Sciences, Bangalore. 1995.

[62]Saxena J C, Rai S, Srivastava K M, Sinha S R. Resistance in the field populations of the diamond back moth to some commonly used synthetic pyrethroids. 1989.

[63]Sethi A, Dilawari V K. Spectrum of insecticide resistance in whitefly from upland cotton in Indian subcontinent. 2008.

[64]Singh D, Singh O, Denholm I, Russell D, Sohal B S, Sarao P S, Sharma N. Monitoring of insecticide resistance and esterase variations in cotton whitefly *Bemisia tabaci* (Gennadius) from Punjab. Proc Natn Conf: Plant Protection New Horizons in the Millennium. 2001:22–23.

[65]Singh M, Kang B K, Sharma S. Status of Insecticide Resistance in *Lipaphis erysimi* (Kalt.) on Rapeseed-mustard. Pesticide Research Journal. 2021;**33**(2): 105–110.

[66]Sparks T C, Thompson G D, Larson L L, Kirst H A, Jantz O K, Worden T V, Hertlein M B, Busacca J D. Biological characteristics of the spinosyns: A new naturally derived insect control agents. 1995.

[67]Sreelakshmi P, Mathew T B, Muralikrishna P, Paul A. Insecticide resistance in field populations of tobacco caterpillar, *Spodoptera litura* Fabricius (Lepidoptera: Noctuidae). Entomon. 2017;**42**(1): 41–46.

[68]Stone G D. Biotechnology and the political ecology of information in India. Human Organization. 2004;**63**(2): 127–140.

[69]Sunitha V, Singh T V K, Supriya G B, Satyanarayana J (2020). Insecticide resistance monitoring of diamond back moth, *Plutella xylostella* (Linn.) in Delhi population. Journal of Entomology and Zoology Studies. 2020; **8**(5): 1706–1712.

[70]Tamilselvan R, Kennedy J S, Suganthi A. Monitoring the resistance and baseline susceptibility of *Plutella xylostella* (L.)(Lepidoptera: Plutellidae) against spinetoram in Tamil Nadu, India. Crop Protection. 2021;**142**:105491.

[71]Taquet A, Delatte H, Barrès B, Simiand C, Grondin M, Jourdan-Pineau H. Insecticide resistance and fitness cost in *Bemisia tabaci* (Hemiptera: Aleyrodidae) invasive and resident species in La Réunion Island. Pest Management Science. 2020; **76**(4):1235–1244.

[72]Vanisree K, Rajasekhar P, Upendhar S, Rao G R, Rao V S. (2011). Insecticide resistance in chilli thrips, *Scirtothrips dorsalis* in Andhra Pradesh. Indian J Plant Prot. 2011;**39**:239–241.

[73]Verma A N, Sandhu G S. Chemical control of diamond-back-moth, *Plutella maculipennis* (Curtis). 1968.

INNOVATIONS IN CONTROLLED ENVIRONMENT AGRICULTURE: BUILDING SUSTAINABLE URBAN FOOD FUTURES

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Abstract

Controlled Environment Agriculture (CEA) represents a new frontier in food production, offering sustainable alternatives to conventional farming in an era of climate change, urbanization, and shrinking arable land. CEA integrates advanced technologies—hydroponics, aeroponics, vertical farming units, rooftop cultivation, and plant factories—to optimize crop growth by regulating temperature, humidity, CO_2, and light. This chapter explores the evolution of CEA, recent innovations, and their potential in ensuring food security. Special emphasis is placed on the Indian context, highlighting adoption opportunities for farmers, feasibility challenges, and the role of Artificial Intelligence (AI) and Internet of Things (IoT) in enhancing efficiency. Examples of hydroponic and aeroponic systems, environmental optimization strategies, and case studies of global and Indian markets are discussed. The chapter concludes by addressing sustainability, energy use, and policy integration, underscoring how CEA can reshape urban food systems and empower smallholder farmers.

Keywords-Controlled Environment Agriculture (CEA), Vertical Farming, Hydroponics, Aeroponics, Urban Agriculture, Artificial Intelligence (AI), Sustainability, Indian Agriculture

1. Introduction

Agriculture has always been the backbone of human civilization, but rapid population growth, urbanization, and climate change are forcing us to rethink how food is produced and distributed. By 2050, the world's population is projected to reach nearly 10 billion, with 68% of people living in urban areas. This shift raises urgent questions: How can we grow enough food in cities where land is scarce? How can farmers adapt to new systems that use fewer resources but still deliver higher yields?

One of the most promising solutions is **Controlled Environment Agriculture (CEA)**. Unlike traditional farming, where crops depend heavily on external conditions, CEA involves growing plants in enclosed or semi-enclosed spaces where factors such as temperature, humidity, light, and nutrients are carefully monitored and controlled. These systems range from simple rooftop greenhouses to highly advanced **Plant Factories with Artificial Lighting (PFALs)**.

CEA's potential lies not only in **yield improvement** but also in **sustainability**. Compared to open-field farming, CEA can reduce water use by up to 90%, minimize pesticide dependency, and increase production per square meter by 10 to 100 times. Furthermore, crops can be grown closer to consumers, reducing transportation costs and post-harvest losses.

In recent years, **India has also begun experimenting with vertical farming, hydroponics, and rooftop gardening**, particularly in metropolitan areas such as Delhi, Bengaluru, and Hyderabad. For Indian farmers, especially those facing fragmented landholdings and erratic climate patterns, CEA provides a way to diversify income and enter into high-value markets such as exotic vegetables, medicinal plants, and leafy greens. However, adoption remains slow due to challenges like high initial investment, limited technical knowledge, and energy demands.

1.1 Evolution of Controlled Environment Agriculture (CEA) and Vertical Farming

Controlled Environment Agriculture is not a new concept—it has its roots in ancient practices. Early civilizations used **protected cultivation methods** like Roman glasshouses and Chinese hotbeds to extend growing seasons. However, the **modern scientific framework** of CEA emerged during the late 20th century, when scientists began experimenting with hydroponics, aeroponics, and artificial lighting systems.

The idea of **vertical farming**, which is now central to CEA, was popularized by Columbia University professor **Dickson Despommier** in the late 1990s. He envisioned skyscraper farms in urban centers that could feed thousands of people while reducing the environmental burden of conventional farming. Since then, technological progress in **LED lighting, climate control systems, automation, and nutrient delivery** has brought this vision closer to reality.

Today, vertical farming is practiced in diverse forms—from **multi-layer hydroponic greenhouses in Japan and Singapore**, to large-scale plant factories in the United States, and rooftop farms across Europe. India too has begun adopting these methods, with urban startups and research institutions exploring rooftop hydroponics and indoor vertical racks to produce high-value vegetables and herbs.

1.2 Addressing Global Challenges: Urbanization, Population Growth, and Food Security

The world is facing unprecedented challenges in food production. By **2050**, the global population is expected to cross **9.7 billion**, creating an additional demand for food that traditional farming systems may not be able to meet. Several critical issues make this situation urgent:

- **Urbanization:** Two-thirds of the population will live in cities, where farmland is scarce.
- **Land Scarcity:** Arable land per capita has been declining due to urban expansion, soil degradation, and climate change.

- **Water Shortages:** Agriculture already consumes nearly **70% of global freshwater resources**, and future demand will exceed supply in many regions.
- **Climate Change:** Unpredictable weather, rising temperatures, and extreme events threaten open-field agriculture.
- **Food Security and Nutrition:** Global diets are changing, with higher demand for fresh vegetables, fruits, and nutrient-dense crops.

Studies suggest that the environmental impact of food production, including greenhouse gas emissions, could increase by **50–90% by 2050** if current farming practices continue. This makes it critical to find **scalable, sustainable, and resource-efficient farming systems**.

CEA addresses these concerns by offering:

✓ Year-round production independent of external climate

✓ Reduced water and land use

✓ Lower pesticide requirements

✓ Shorter supply chains for fresher produce

1.3 Vertical Farming as a Technological Response

Vertical farming is often seen as the most advanced expression of CEA. In this system, crops are grown in **vertically stacked layers**, often using hydroponic or aeroponic techniques, under controlled environmental conditions.

Key features of vertical farming include:

- **Space efficiency:** Allows farming in urban buildings, warehouses, or even shipping containers.
- **Climate control:** Uses sensors and automation to regulate temperature, humidity, CO_2, and lighting.
- **High productivity:** Can achieve **10–100 times more yield per unit area** than traditional farms.
- **Resource conservation:** Saves **70–95% of water** and reduces fertilizer waste by recycling nutrients.
- **Urban proximity:** Brings production closer to consumers, cutting transportation costs and ensuring fresher produce.

Globally, vertical farming is being used to grow **leafy greens, herbs, tomatoes, strawberries, and medicinal plants**. In India, early adopters are focusing on lettuce, spinach, basil, cherry tomatoes, and exotic herbs—high-value crops that can fetch premium prices in urban markets and restaurants.

1.4 Advances in Technology and Market Integration

The rapid development of **digital agriculture technologies** has played a vital role in making Controlled Environment Agriculture (CEA) and vertical farming more efficient and profitable. Key technological advances include:

- **LED Lighting Innovations:**
  New energy-efficient **red-blue spectrum LEDs** reduce electricity costs while enhancing photosynthesis and crop quality. Smart LEDs can now adjust spectrum and intensity automatically for different crop stages.
- **Sensors and IoT Platforms:**
  Wireless sensors continuously measure temperature, humidity, light intensity, CO_2 levels, and nutrient concentration. These sensors send real-time data to **IoT dashboards**, allowing farmers to monitor farms remotely through smartphones or computers.
- **Artificial Intelligence (AI):**
  AI-driven algorithms predict crop growth, optimize lighting and irrigation, and even detect early signs of nutrient deficiency or disease through **image recognition**. AI helps minimize waste and maximize yield per square meter.
- **Automation and Robotics:**
  Vertical farms are increasingly using **automated irrigation systems, nutrient dosing pumps, and robotic arms** for planting, harvesting, and packaging. This reduces dependence on labor and improves operational consistency.
- **Blockchain and Traceability:**
  With growing demand for food transparency, blockchain technology is being used to track produce from farm to table, boosting consumer trust and enabling premium pricing for urban-farmed products.

From a market perspective, **consumer demand for pesticide-free, fresh, and locally produced vegetables** is pushing CEA adoption. Urban restaurants, supermarkets, and e-commerce platforms are emerging as key buyers. In India, metropolitan cities like **Hyderabad, Bengaluru, and Delhi NCR** are already witnessing a rise in vertical farming startups that supply exotic greens to hotels and premium stores.

1.5 Collaborative Initiatives and Industry Development

The global expansion of CEA has been fueled by **collaboration between research institutions, entrepreneurs, and policymakers.** Examples include:

- **International Forums:** Events like *Indoor Ag-Con* and *CEAg World* serve as knowledge-sharing platforms for innovators, researchers, and investors.
- **Industry Alliances:** Organizations such as the *CEA Alliance* and *Urban AgriTech* support research, set safety standards, and lobby for supportive policies.
- **Food Safety Networks:** Groups like the *CEA Food Safety Coalition* are working on standardized protocols for pesticide-free urban produce.

In India, agricultural universities, government departments, and private companies are beginning to work together. Initiatives by **ICAR, state horticulture departments, and startups** are supporting farmers through training, subsidies, and technology demonstrations. Collaborations with **energy and tech companies** are also exploring renewable-powered CEA systems.

Such partnerships are essential because they bridge the gap between **scientific research and practical farming applications**, helping farmers adopt modern systems at lower risk.

1.6 Persistent Challenges and the Need for System-Level Approaches

Despite its promise, CEA is not without challenges. Some of the key hurdles include:

- **High Initial Investment:** Setting up a commercial vertical farm requires significant capital for infrastructure, LEDs, automation, and climate control systems.
- **Energy Consumption:** Artificial lighting and HVAC systems can be energy-intensive, raising both operational costs and environmental concerns.
- **Skill Gaps:** Many farmers and workers are unfamiliar with hydroponics, aeroponics, or digital farming tools. Training and extension services are essential.
- **Consumer Awareness:** While urban elites are open to buying hydroponic produce, wider market acceptance is still limited in India due to lack of awareness.
- **Logistics and Distribution:** To be profitable, farms must integrate with **cold chains, e-commerce, and direct marketing channels**, which require planning and investment.

Therefore, a **system-level approach** is needed, considering not just technology, but also **policy support, training, financing options, and consumer education.** By addressing these aspects together, CEA can become a mainstream contributor to food security.

2: Controlled Environment Agriculture (CEA) Systems

2.1 Concept and Scope

Controlled Environment Agriculture (CEA) is a modern farming approach where crops are grown in **climate-managed spaces** such as greenhouses, vertical farms, and rooftop setups. Unlike open-field farming, which is exposed to unpredictable weather, CEA creates **stable indoor environments** with regulated temperature, humidity, light, and nutrient supply.

This allows farmers to:

- Grow crops **year-round** regardless of season.
- Reduce the use of pesticides by minimizing pest entry.
- Conserve resources like water and nutrients through recycling.
- Produce more food in smaller spaces, especially in urban settings.

In short, CEA transforms farming into a **precise, technology-driven process** that ensures **consistent productivity and higher-quality crops.**

2.2 Global Growth and Market Trends

CEA has become a billion-dollar industry worldwide. The global indoor farming market was valued at around **USD 27 billion in 2018** and is projected to grow at nearly **9–10% annually** (2020–2025 estimates).

- **Europe and North America** lead in adoption, with advanced greenhouse networks and commercial vertical farms.
- **Asia (China, Japan, Singapore, India)** is rapidly catching up due to urbanization and land scarcity.
- In **India**, the rise of hydroponics startups in **Hyderabad, Delhi NCR, and Bengaluru** is showing strong market potential for fresh, chemical-free vegetables.

Consumers are increasingly willing to pay premium prices for **safe, fresh, and locally grown produce**, making CEA an attractive investment.

2.3 Types of CEA Systems

2.3.1 Vertical Farming Systems (VFs)

Vertical farming uses **stacked shelves, A-frames, or tower systems** to grow crops in multiple layers, multiplying yield per square meter of land.

Features:

- Can grow crops 10–100 times more per unit area than field farming.
- Uses **70–95% less water** than soil-based cultivation.
- Ideal for **leafy greens, herbs, strawberries, and tomatoes.**

Example (India): Startups in Hyderabad are supplying fresh lettuce, basil, and spinach to restaurants using hydroponic vertical racks.

2.3.2 Rooftop Greenhouses and Gardens (RTGs)

Rooftop cultivation is a simple but effective model for cities with limited land. Farmers or entrepreneurs can convert rooftops into **hydroponic greenhouses or soil-based gardens.**

Benefits:

- Reduces building heat in summer and insulates in winter.
- Enhances **urban green cover** and reduces pollution.
- Provides **local fresh vegetables** directly to residents or nearby markets.

Example (India): In Mumbai and Bengaluru, rooftop hydroponic farms supply salad greens directly to housing societies and hotels.

2.3.3 Plant Factories with Artificial Lighting (PFALs)

These are **high-tech, fully enclosed indoor farms** (often warehouses) that rely 100% on **artificial lighting** instead of sunlight.

Key Characteristics:

- Advanced control of temperature, humidity, CO_2, and nutrients.

- Extremely high yields and predictable production cycles.
- Main crops: lettuce, microgreens, medicinal plants, strawberries.

Challenges:

- High energy costs (lighting and air conditioning take up to 50% of expenses).
- Requires **skilled technical staff** to manage operations.

Future in India: With solar energy and government subsidies, PFALs can become feasible in urban centers where land is very expensive.

2.3.4 Hybrid and Emerging Systems

Some farms combine methods to balance cost and productivity:

- **Greenhouses + Hydroponics** → affordable and efficient.
- **Aquaponics** → integrates fish culture with hydroponics in a closed loop.
- **Aeroponics** → roots are misted with nutrients, saving 90% more water than hydroponics.

These hybrid models are gaining attention among **progressive Indian farmers** and agri-startups.

2.4 Economic Feasibility for Farmers

The cost of setting up a CEA system depends on the type:

- **Hydroponic Vertical Rack (small unit, 500 sq ft):** ₹3–4 lakh
- **Commercial Rooftop Greenhouse (1000 sq ft):** ₹6–8 lakh
- **Plant Factory (1000 sq ft, fully automated):** ₹15–20 lakh

Return on Investment (ROI):

- Farmers can recover setup costs in **2–3 years** if connected to urban markets.
- Leafy greens and herbs often generate **₹50,000–₹1,00,000 per month per 1000 sq ft**, depending on crop choice and marketing.

3: Soilless Cultivation Techniques in Controlled Environment Agriculture

3.1 Introduction

One of the biggest advantages of Controlled Environment Agriculture (CEA) is the ability to grow crops **without soil**. Instead of depending on natural soil quality, plants are provided with carefully managed nutrients through water, mist, or integrated systems.

This ensures:

- Faster growth,
- Higher yields,
- Efficient use of water and fertilizers,
- Minimal risk of soil-borne diseases.

The three most popular soilless systems are **Hydroponics, Aeroponics, and Aquaponics**.

3.2 Hydroponics – The Backbone of Soilless Farming

Hydroponics means growing plants in **nutrient-rich water solutions** instead of soil. The plant roots are supported in an inert medium like **coco peat, perlite, or rockwool**, while nutrients are delivered in water.

3.2.1 Key Components

- **Nutrient Solution:** Contains all essential macro (N, P, K, Ca, Mg, S) and micro (Fe, Zn, Mn, B, Mo) nutrients.
- **pH & EC Control:** pH kept between 5.5–6.5; EC adjusted depending on crop.
- **Growing Media:** Provides root support (cocopeat, clay balls, rockwool).

3.2.2 Major Types of Hydroponics

1. **Nutrient Film Technique (NFT):** Shallow nutrient film flows past roots (best for lettuce, spinach, herbs).
2. **Deep Water Culture (DWC):** Roots float in oxygen-rich water (ideal for tomatoes, cucumbers).
3. **Drip System:** Nutrient solution drips near roots (used for strawberries, capsicum).
4. **Wick System:** Simple, low-cost model for small-scale farmers.

3.2.3 Advantages

- Uses up to **90% less water** than soil farming.
- Yields up to **10 times higher** per unit area.
- Faster crop cycles, allowing multiple harvests per year.

3.3 Aeroponics – Farming in Air

Aeroponics is a **high-tech version of hydroponics** where plant roots hang in the air and are sprayed with a fine mist of nutrient solution.

3.3.1 Features

- Roots get maximum oxygen exposure, leading to faster growth.
- Water use efficiency is even higher than hydroponics (saves up to **95% water**).
- Produces nutrient-rich, cleaner crops.

3.3.2 Challenges

- Needs precise misting equipment.
- Higher setup and maintenance costs.
- More suited to commercial farms and research centers.

3.3.3 Example Crops

- Lettuce, spinach, kale, and strawberries.

3.4 Aquaponics – Plants + Fish Together

Aquaponics combines **aquaculture (fish farming)** with hydroponics in one **closed-loop system**.

3.4.1 How It Works

- Fish produce waste (ammonia).
- Bacteria convert ammonia → nitrite → nitrate.
- Plants absorb nitrates as nutrients.
- Clean water returns to the fish tanks.

3.4.2 Advantages

- Produces both **fish and vegetables**.
- Very sustainable and eco-friendly.
- Almost zero waste – complete recycling of water and nutrients.

3.4.3 Limitations

- More complex management (must balance fish and plant health).
- Requires regular monitoring of water quality (pH, oxygen, ammonia levels).

3.5 Comparison of Systems

Feature	Hydroponics	Aeroponics	Aquaponics
Water use	90% less than soil	95% less than soil	Almost closed-loop
Cost	Medium	High	Medium–High
Best for	Leafy greens, herbs	Lettuce, strawberries	Fish + vegetables
Technical demand	Moderate	High	Moderate–High
Profitability	High in urban markets	High (if large scale)	Good (dual income)

3.6 Economic Feasibility in India

- **Hydroponics (small 500 sq ft unit):** Setup ₹3–4 lakh, monthly income ₹40,000–60,000.
- **Aeroponics (1000 sq ft unit):** Setup ₹10–12 lakh, profitable mainly for high-value crops (e.g., exotic lettuce, strawberries).
- **Aquaponics (1000 sq ft unit with fish):** Setup ₹6–8 lakh, dual income (fish + veggies) can give ₹60,000–80,000/month.

Chapter 4: Environmental Optimization in Controlled Environment Agriculture (CEA)

4.1 Introduction

In CEA systems such as **greenhouses, vertical farms, and plant factories**, controlling the growing environment is the key to success. Unlike open-field farming, plants in CEA are not exposed to natural climate. Instead, their **temperature, humidity, light, airflow, and nutrients** are carefully managed to maximize growth.

This chapter explains the main environmental factors that must be optimized for successful production.

4.2 Temperature Management

- **Role of temperature:** It influences plant germination, flowering, fruiting, and yield.
- **Optimal range:** Most vegetables prefer 18–28°C.
- **Effects of imbalance:**
  - Too high → slows growth, reduces yield.
  - Too low → delays germination, increases disease risk.

Practical Approaches

- **Greenhouses:** Use heaters in winter and shade nets/cooling pads in summer.
- **Vertical farms/PFALs:** Automated HVAC systems maintain stable conditions.
- **Smart Controls:** Stressing plants with slightly cooler or drier conditions before harvest can improve taste and nutrient quality (e.g., tomatoes, leafy greens).

4.3 Humidity and Plant Water Use

Vapour Pressure Deficit (VPD)

- VPD = difference between moisture in the air vs. what plants release.
- **Ideal range:** 0.8–1.0 kPa.

If humidity is too high (low VPD):

- Plants transpire less; risk of fungal diseases increases.

If humidity is too low (high VPD):

- Plants lose too much water, stomata close, growth slows.

Practical Approaches

- Use foggers or misting systems to increase humidity.
- Use fans and ventilation to reduce excess humidity.

4.4 Airflow and Carbon Dioxide (CO_2) Management

- Proper airflow ensures **uniform temperature** and avoids fungal growth.
- **Recommended airflow:**
  - General: 0.3–0.5 m/s
  - Tomato seedlings: up to 0.7 m/s
- Excessive airflow (>1.0 m/s) can stress plants.

CO_2 Enrichment

- Raising CO_2 levels (to 800–1000 ppm) can **increase yields by 20–30%**.
- Used in closed vertical farms and greenhouses with good sealing.

4.5 Energy and Cooling Needs

- **HVAC (Heating, Ventilation, Air Conditioning):** Biggest cost factor in vertical farms (up to

70% in cold regions, ~50% in warm regions).

- **Cooling options:**
    - Evaporative cooling pads (greenhouses in hot areas).
    - Indirect evaporative cooling (energy efficient, best in dry climates).
    - Fogging and misting systems.

Smart Energy Strategies

- Passive cooling with shading, natural ventilation.
- Insulation to reduce heat loss.
- Use of renewable energy (solar, wind, biogas) to cut costs.

4.6 Light Optimization

- Light controls **photosynthesis, growth speed, and crop quality**.
- **LED lights** are widely used because they save 50–70% energy compared to traditional lights.
- Red + Blue spectrum LEDs → maximize photosynthesis.
- White LEDs → improve flavor and appearance of crops.

4.7 Automation and Sensors

Modern farms use **sensors + IoT + AI** for environmental monitoring.

Parameters Monitored:

- Temperature
- Humidity
- Light intensity
- Soil/solution moisture
- CO_2 concentration

Automation Benefits

- Sensors + AI controllers adjust fans, lights, and irrigation automatically.
- Reduces labor cost and improves consistency.
- Example: Automated systems can keep temperature within ±0.2°C and humidity within ±1%.

4.8 Summary of Environmental Control Methods

Factor	Target Range / Method	Tools Used
Temperature	18–28°C	HVAC, shading, heating
Humidity/VPD	0.8–1.0 kPa	Foggers, fans, sensors
Airflow	0.3–0.5 m/s	Fans, vents
CO_2	800–1000 ppm	CO_2 injectors, sealed env.
Light	Spectrum control with LEDs	Red + Blue/White LEDs
Energy Saving	Renewable energy, insulation	Solar, wind, passive tech

5: Environmental Sustainability in Controlled Environment Agriculture (CEA)

5.1 Introduction

Controlled Environment Agriculture (CEA) — including greenhouses, vertical farms, and plant factories — offers huge benefits in terms of **higher yields, reduced land use, and lower pesticide dependence**. However, these systems also consume a lot of **energy for lighting, heating, cooling, and ventilation**, which can increase their carbon footprint.

This chapter explains the sustainability aspects of CEA, comparing it with traditional farming, and highlights strategies to make CEA more eco-friendly.

5.2 Advantages of CEA for Sustainability

- **Water efficiency:** Uses up to **90–95% less water** than soil farming, thanks to hydroponics/aeroponics recirculation.
- **Reduced pesticide use:** Enclosed systems prevent pest attacks, so fewer chemicals are required.
- **Land savings:** Vertical stacking reduces land use by up to **300%**, important in cities.
- **Local food production:** Grown near consumers, reducing transportation emissions.

5.3 Limitations of CEA

Despite these benefits, CEA faces some **environmental concerns**:

- **High energy demand:** Artificial lights, HVAC, and pumps increase electricity use.
- **Carbon emissions:** If energy comes from fossil fuels, the carbon footprint may exceed open-field farming.
- **Cost of renewable adoption:** Solar/wind installations require high initial investment.

5.4 Comparing Traditional vs. Controlled Systems

System Type	GWP* (kg CO_2-eq / kg food)	Notes
Open-field cultivation	~0.37	Lowest footprint, but lower yields
Passive greenhouse	~1.10	More inputs but higher production
Heated greenhouse (CEA)	~2.13	Energy demand increases footprint

*GWP = Global Warming Potential

👉 This shows that while **open-field farming** has the lowest emissions, **CEA systems balance this by producing more per unit area, closer to consumers, and with less water/pesticides**.

5.5 Strategies for Reducing Environmental Impact

5.5.1 Renewable Energy Integration

- Solar panels on rooftops or nearby farms.
- Wind turbines in rural-urban edge areas.
- Biogas plants to power greenhouse heating.
  ➞ Can reduce **carbon footprint by 50–70%**.

5.5.2 Energy-Efficient Designs

- Thermal insulation materials reduce heating/cooling load.
- Shading devices cut cooling needs by up to **30%**.
- Passive ventilation in dry regions lowers HVAC cost by ~31%.

5.5.3 LED Lighting

- LEDs save up to **70% electricity** compared to traditional lights.
- Red + Blue spectrum improves yield; White LEDs improve crop quality.
- Can cut emissions by up to **50%**.

5.5.4 Automation & Smart Controls

- AI and IoT sensors optimize energy use.
- Automated controllers reduce wastage by running fans, pumps, and lights only when required.
- Labor costs (which are ~50% of operational costs) can also be reduced.

5.6 Challenges in Assessing Sustainability

- **Data gaps:** Many studies measure only certain crops (like lettuce, tomato), not the full range of CEA crops.
- **Boundary issues:** Some studies count only "farm-gate" emissions, while others include transport & retail.
- **Technology differences:** Newer LEDs and renewable systems are often not considered in older studies.

6: Environmental Impact Assessment and Future Sustainability of CEA

6.1 Introduction

Controlled Environment Agriculture (CEA) — including vertical farms, rooftop gardens, and plant factories — is often seen as a sustainable alternative to conventional farming. But to truly evaluate its environmental performance, researchers use a method called **Life Cycle Assessment (LCA)**.

LCA helps us measure the total impact of a system, from **construction and operation to disposal** — including energy use, carbon emissions, water, and waste. This chapter explains what LCA shows about CEA, compares it with open-field farming, and suggests how future CEA systems can be made greener.

6.2 Environmental Advantages of CEA

CEA offers several key sustainability benefits:

- **Reduced transport emissions:** Food is grown near cities, cutting "food miles."
- **Lower water use:** Hydroponics and aeroponics recycle water.
- **Less pesticide use:** Enclosed systems reduce pest entry.
- **High yield per unit land:** Vertical stacking and year-round production make CEA land-efficient.

6.3 Environmental Limitations of CEA

- **Energy dependency:** Heating, cooling, lighting, and pumping require large amounts of electricity.
- **Carbon footprint:** In fossil fuel–based grids, CEA's greenhouse gas (GHG) emissions may be higher than open-field systems.
- **Construction footprint:** Setting up high-tech farms requires steel, plastics, and insulation, which add to embedded emissions.

6.4 Comparative LCA Findings

A global review (Clune et al., 2017) compared the **Global Warming Potential (GWP)** of food systems:

Production System	GWP (kg CO_2-eq per kg food)	Notes
Open-field cultivation	~0.37	Lowest impact but weather dependent
Passive greenhouse	~1.10	Moderate impact, partly efficient
Heated greenhouse / PFAL	~2.13	High due to energy demand

🔎 **Takeaway:** Open-field is lowest in emissions, but **CEA compensates by producing more food per m², with higher quality and proximity to cities.**

6.5 Strategies to Improve CEA Sustainability

6.5.1 Renewable Energy Use

- Solar PV panels on rooftops of vertical farms.
- Wind energy in peri-urban locations.
- Biogas/biomass-based heating for greenhouses.

➡ Potential emission reduction: **50–70%**.

6.5.2 Energy-Efficient Infrastructure

- **Insulated walls & glazing:** Reduce heating/cooling needs.
- **Shading nets & reflective surfaces:** Minimize summer loads.
- **Double-skin façades:** Trap heat in winter, save cooling in summer.

6.5.3 Smart Lighting

- **LEDs with dynamic spectrum control** → Use only the light plants need.
- **Daylight integration** in greenhouses.
- Can cut electricity demand by **up to 75%**.

6.5.4 Automation & AI

- AI-powered models predict crop needs.
- Automated HVAC & irrigation reduce waste.
- IoT sensors track CO_2, humidity, pH, and nutrients in real-time.

6.6 Challenges in LCA Studies

- **Method variation:** Some LCAs count only farm operations, others include construction.
- **Crop diversity:** Most studies focus on lettuce and tomato; other crops underrepresented.
- **Rapid tech change:** Older studies underestimate benefits of LEDs, renewable energy, and AI.
- **Regional variations:** Sustainability outcomes differ in solar-rich India vs. energy-intensive Europe.

6.7 Future Directions for Sustainable CEA

- **Integration with renewable energy microgrids** in cities.
- **Circular economy approach:** Recycling plastics, using biodegradable substrates, nutrient recovery.
- **Hybrid models:** Combining rooftop solar, rainwater harvesting, and aquaponics for zero-waste systems.
- **Policy support:** Incentives for solar-powered farms, subsidies for LEDs, and carbon credits for urban farmers.

7: Summary and Conclusions

7.1 Key Learnings from Controlled Environment Agriculture (CEA)

Controlled Environment Agriculture (CEA) — including vertical farms, greenhouses, rooftop gardens, and plant factories — is emerging as a **transformative farming system** for the future. It addresses challenges such as **urban population growth, shrinking farmland, and climate uncertainty**.

From the review of different systems and technologies, the following points are clear:

- **High productivity per unit land**: CEA can yield up to **10–100 times more food** than open-field farming.
- **Water savings**: Hydroponics and aeroponics reduce water use by **70–95%**, which is critical in

water-scarce regions like India.

- **Food quality & safety**: Enclosed systems produce clean, pesticide-free, nutrient-rich food.
- **Urban resilience**: CEA reduces food miles and provides fresh produce close to consumers, cutting transport costs and emissions.

7.2 Current Barriers to Adoption

Despite its potential, several hurdles slow down large-scale adoption of CEA:

- **High initial investment** for structures, sensors, and lighting.
- **Energy-intensive operations**, particularly for fully artificial lighting in Plant Factories with Artificial Lighting (PFALs).
- **Skill requirements**, as farmers need training in hydroponics, automation, and data-driven crop management.
- **Market access**, since consumers in some regions may be unfamiliar with CEA-grown produce.

7.3 Pathways to Future Sustainability

To make CEA a **mainstream contributor to food security**, the following strategies are recommended:

1. **Renewable Energy Integration** – Solar panels, wind energy, and biomass heating to cut carbon emissions.
2. **Energy Efficiency** – Use of LED grow lights, insulation, passive cooling, and efficient HVAC systems.
3. **Digital Agriculture** – AI, IoT, and remote sensing for predictive crop management and automated climate control.
4. **Policy & Incentives** – Government support through subsidies, tax breaks, and inclusion of CEA in urban planning policies.
5. **Circular Systems** – Adoption of aquaponics, waste recycling, and nutrient recovery to reduce environmental impact.

7.4 Conclusion

Controlled Environment Agriculture is not merely a futuristic concept — it is already shaping how cities and peri-urban regions grow food. While **open-field farming will remain essential**, CEA offers **resource efficiency, food safety, and year-round production** that traditional methods cannot always provide.

By **reducing water use by up to 95%, cutting land requirements by up to 300%, and providing pesticide-free crops**, CEA represents a **sustainable solution** to feeding growing urban populations.

However, for CEA to be truly sustainable and profitable, **energy optimization and integration with renewable resources** are essential. If these challenges are addressed, CEA will play a **key role in Agriculture 2.0**, creating resilient, eco-friendly food systems for the future.

References

1. Alam, M., Rahman, M., & Kumar, R. (2023). *Advances in hydroponics and sustainable urban agriculture: Opportunities and challenges.* Journal of Cleaner Production, 398, 136722.
2. Armanda, D. T., Guinée, J. B., & Tukker, A. (2019). *The second green revolution: Innovative urban agriculture systems.* Resources, Conservation and Recycling, 147, 143–156.
3. Benis, K., Reinhart, C., & Ferrão, P. (2017). *Building-integrated agriculture (BIA): An overview of urban rooftop farming systems.* Renewable and Sustainable Energy Reviews, 75, 1195–1206.
4. Burritt, R., Christ, K., & Rimmel, G. (2025). *Sustainability challenges in vertical farming: Energy and economics.* Agricultural Systems, 212, 103692.
5. Clune, S., Crossin, E., & Verghese, K. (2017). *Systematic review of greenhouse gas emissions for different fresh food categories.* Journal of Cleaner Production, 140, 766–783.
6. Dsouza, R., et al. (2023). *Socio-economic and environmental impacts of controlled environment agriculture: A systems approach.* Agricultural Systems, 207, 103614.
7. Fei, X., Sun, Z., & Zhang, L. (2025). *Global trends in indoor farming markets: Energy and efficiency perspectives.* Journal of Agribusiness and Development, 44(2), 55–71.
8. Graamans, L., Baeza, E., van den Dobbelsteen, A., Tsafaras, I., & Stanghellini, C. (2018). *Plant factories versus greenhouses: Comparison of resource use efficiency.* Agricultural Systems, 160, 31–43.
9. Gu, B., Zhang, X., & Bai, X. (2021). *Urbanization and food security in the 21st century.* Nature Food, 2(1), 7–13.
10. Insights (2022). *Global CEA Market Report.* CEAg World Conference Proceedings.
11. Kozai, T., Niu, G., & Takagaki, M. (2019). *Plant Factory: An Indoor Vertical Farming System for Efficient Quality Food Production.* Academic Press.
12. Kumar, P., Singh, R., & Yadav, S. (2023). *Aeroponics and its potential for sustainable food systems.* Indian Journal of Agricultural Sciences, 93(5), 877–885.
13. Mina, K., et al. (2023). *Environmental impacts of global food demand: A scenario analysis.* Science of the Total Environment, 857, 159330.
14. Rajalakshmi, P., Sharma, A., & Rao, V. (2022). *Aquaponics: Closed-loop systems for sustainable farming.* Agricultural Reviews, 43(3), 324–335.
15. Shamshiri, R. R., et al. (2018). *Advances in greenhouse automation and controlled environment agriculture: A review.* Biosystems Engineering, 164, 93–112.
16. Srivastava, P., & Mathur, A. (2023). *Hydroponic farming in India: Technologies and profitability*. Current Science, 125(10), 1576–1585.
17. Tong, Y., et al. (2026). *Productivity gains in vertical farming systems: A meta-analysis.* Agricultural Reviews, 48(1), 12–29.
18. Vernon, M., et al. (2023). *Optimizing climate control in CEA to improve flavor and nutrition.*

Horticultural Science, 58(2), 245–258.

19. Zarei, M., et al. (2019). *Life cycle assessment of greenhouse systems for vegetable production.* Journal of Environmental Management, 241, 406–414.
20. Zhang, X., & Li, Y. (2019). *LED lighting and CO_2 enrichment in vertical farming: Crop yield and sustainability impacts.* Frontiers in Plant Science, 10, 1196.

NATURAL FARMING: A PROMISING AND SUSTAINABLE ALTERNATIVE TO CONVENTIONAL AGRICULTURE

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Introduction

The increasing global population and economic development are driving a significant rise in food demand, particularly in low- and middle-income countries like India[1]. Currently, India accounts for approximately 17.71% of the world's total population[2] and is projected to experience a 33% increase, rising from 1.2 billion in 2010 to an estimated 1.6 billion by 2050[3]. To ensure that India can sustain its ability to produce food, crop production must keep pace with rising demand. From 1961 to 1999, enhancements in crop production were achieved through a dual approach: intensification, which involved increasing yields per unit of land and extensification, which focused on expanding the area under cultivation[4]. However, the increased use of irrigation and synthetic fertilizers, particularly since the Green Revolution, has led to inefficiencies in resource utilization [5]. Northern India has been identified as a global hotspot for low nutrient efficiency. Additionally, only about 16% of land in India is available for potential agricultural conversion, much of which is unsuitable for cultivation due to geographical constraints such as mountainous or urban areas. Consequently, to satisfy growing food demands on a decreasing amount of arable land, it is imperative to enhance the efficiency of crop production[6]. The intensive cultivation practices, coupled with prolonged chemical inputs, have led to various issues, like the deterioration of soil physical properties and the emergence of multi-nutrient deficiencies. Additionally, the rising costs of chemical inputs have Increased financial burdens, especially among small and medium-scale farmers. Consequently, adopting scientifically proven soil management practices is essential for ensuring global food security [7-9]. Addressing these challenges requires an urgent transition from conventional chemical-based agriculture towards integrated nutrient management and sustainable farming methods.

Agriculture is fundamental to India's journey toward Atma Nirbharta (self-reliance), with farmers playing a crucial role in this initiative. The government's initiatives have consistently aimed at uplifting, empowering and ensuring the stability of farmers across technical, economic and social dimensions. In this context, we are actively exploring various approaches to achieve ecologically sustainable and economically viable agricultural practices. Natural farming is one such approach that shows promise in fulfilling these objectives. Natural Farming is a chemical-free agricultural system rooted in Indian tradition and enhanced by modern ecological insights. This approach is recognized as an agroecological, diversified farming method that integrates crops, trees and livestock within a framework of functional biodiversity. It emphasizes the recycling of on-farm biomass, particularly through practices like biomass mulching and the use of cow dung and urine formulations. Natural Farming focuses on maintaining soil aeration while eliminating synthetic chemical inputs. This method aims to reduce reliance on purchased resources, making it a cost-effective farming practice with potential for increasing employment and fostering rural development. This approach is seen as a way to tackle the challenges many low-income farmers face in accessing improved seeds and synthetic agrochemicals, while also helping to prevent cycles of debt caused by high production costs, elevated interest rates and fluctuating market prices. These pressures have contributed to a distressing increase in suicides among farmers, with more than 2530 farmers in India having taken their own lives since 1995[10]. In 2010, approximately 3% of adult deaths were attributed to suicide, with rural areas experiencing suicide rates that were double those of urban areas[11]. In addition, there was a positive relationship across states between the proportion of marginal farmers, the production of cash crops and the levels of farmer debt[12]. Moreover, significant negative health effects have been linked to the use of agrochemicals in India[13,14].

Natural Farming

1. Philosophy

The philosophy of natural farming emphasizes working in harmony with nature to produce healthy food, maintain our well-being and preserve the health of the soil. Everything in nature serves a purpose within the ecosystem. Often referred to as "Do Nothing Farming," this approach positions the farmer as a facilitator, with the primary processes carried out by nature itself. This method involves no tillage and avoids the use of herbicides, inorganic fertilizers and pesticides. As a result, the physical labor required can be reduced by up to 80% compared to conventional farming systems. In Japan, Fukuoka initiated natural farming by experimenting with natural processes and following organic methods of crop propagation. He managed to achieve yields comparable to those from chemical farming while preventing soil erosion[15-17]. The core principle of natural farming is to minimize external inputs that degrade soil health. Initially, due to a lack of habitat for many beneficial insects, Fukuoka had to create natural insecticides, such as pyrethrum derived from chrysanthemum roots, to protect his vegetables from pests like cabbage worms and cabbage moths. However, by working in harmony with nature rather than disrupting it, we can ultimately rely on nature to take care of us. Zero-Budget Natural Farming (ZBNF), suggested by Subash Palekar in India[18], shares a similar philosophy but incorporates indigenous supplements. In ZBNF, the soil is enriched with microbial inoculants such as beejamrit and jeevamrit to promote the proliferation of beneficial soil microflora. Additionally, indigenous pesticide preparations, including leaf decoctions mixed with cow urine, such as bramhastram and neemastram are utilized. The fundamental philosophy of natural farming is to foster the growth of beneficial microbes without relying on external fertilizers and agro-chemical pesticides.

2. Definition

According to NITI Aayog, natural farming is a chemical-free, traditional agricultural approach. It is recognized as an agroecological, diversified farming system that incorporates crops, trees, and livestock, while promoting functional biodiversity. Natural Farming can be defined as "chemical- free farming and livestock based." Rooted in agroecology, natural farming optimizes the use of functional biodiversity. It has the potential to increase farmers' income while also offering numerous advantages, including the restoration of soil fertility, improved environmental health and the mitigation or reduction of greenhouse gas emissions. Natural Farming builds on natural or ecological processes that exist in or around farms. Natural farming has following major objectives:

- Preserve natural flora and fauna.
- Restore soil health, fertility and biological life.
- Promote diversity in crop production.
- Utilize land and natural resources (light, air, water) efficiently.
- Promote beneficial insects and microbes in the soil for recycling of nutrients and biological pest and disease control.
- Encourage the integration of local livestock breeds.
- Utilize natural and locally sourced inputs.
- Reduce the input costs of agricultural production.
- Enhance the economic viability for farmers.

3. Miscoceptions

Many stakeholders in agricultural research and development have misconceptions about Natural Farming.

3.1. Natural Farming vs. Organic Farming: Some people think that natural farming is just a part of organic farming, but actually it is a separate concept. Natural Farming focuses on no or minimal tillage, mulching, producing inputs on the farm and the important role of microbes in promoting healthy crop growth, which differs from traditional organic methods.

3.2. Concerns About Food Security: Another common belief is that chemical farming was necessary to avoid food shortages in India during the 1950s and 1960s due to low crop yields. However, this issue was mainly caused by a lack of adequate agricultural research and infrastructure at that time. Recent studies have shown that there is no decrease in yield during the first year of practicing natural farming, which suggests that these concerns are unfounded.

How it is different from organic farming

Organic farming and natural farming are both integral components of agro-ecological systems, often used interchangeably. However, there are key distinctions between the two. Organic farming typically involves the use of commercially available organic inputs, such as bio-fertilizers, which are purchased from external sources. In contrast, natural farming emphasizes the use of bioproducts generated from the farm itself and its surrounding ecosystem, minimizing reliance on external inputs. Organic farming incorporates important agricultural practices like ploughing, fertilizing and weeding. In contrast, natural farming sets itself apart by avoiding tillage and the use of fertilizers entirely. This method helps farming activities work in harmony with natural ecosystems, fostering a better relationship with the environment.

Table 1: Caparison between organic and natural farming

Organic Farming	Natural farming
Organic farming approach is based on the belief that essential nutrients should be supplied through external organic sources, such as manures.	Natural farming method is based on the idea that a healthy balance of microbes and earthworms will naturally meet the nutritional needs of the crops.
In organic farming manures such as farmyard manure (FYM), organic fertilizers, compost, etc are used	While in natural farming the decomposition of crop residues left on the surface by microbes and earthworms helps restore nutrients in the soil over time.
It involves fundamental agricultural practices such as ploughing, turning the soil, mixing of manures and managing weeds physically.	On the other hand, there is no or minimum tillage in natural farming and weeds are managed by growing intercrops, mixed crops and mulching, etc.
The conversion of land from chemical farming to organic farming typically takes between 3 to 6 years, depending on the health of the soil.	There is no specific time requirement to transition from chemical farming to natural farming.
It remains costly because of the need for large quantities of organic manures from external sources and it can also have ecological effects on surrounding environments due to greenhouse gas emissions.	This method relies solely on internal resources, making it one of the most cost-effective farming practices, fully aligned with local biodiversity.

Here is a simplified comparative analysis of the three agri-food systems: chemical-based conventional agriculture, organic farming and natural farming.

Crop Yields

- **Conventional Agriculture:** Focuses on maximizing yields using a lot of land and resources, but this approach can lead to problems like soil degradation.
- **Organic Farming:** Aims for good yields while relying on higher prices to make up for any lower production. It seeks to be sustainable without losing productivity.
- **Natural Farming:** Shows that it's possible to achieve high yields in a sustainable way, focusing on environmental health.

Crop Production Inputs

- **Conventional Agriculture:** Uses chemical fertilizers for nutrients and pesticides for pest control. This can damage soil health by reducing important elements like carbon and beneficial organisms.
- **Organic Farming:** Uses organic materials for nutrients and natural methods to control pests, promoting healthier soil and environment.
- **Natural Farming:** Relies on very few outside inputs and uses resources created on the farm, avoiding harmful chemicals and heavy organic materials.

Seed Varieties

- **Conventional Agriculture:** Often uses improved crop varieties and hybrids, including genetically modified organisms (GMOs), to boost yields.
- **Organic Farming:** Avoids hybrids and GMOs, choosing non-GMO seeds that do not need chemical inputs.
- **Natural Farming:** Does not use improved or GMO seeds, focusing instead on traditional varieties that are suited to local conditions.

Water Management

- **Conventional and Organic Agriculture**: Mainly depend on rainfall or irrigation, which can be costly and inefficient for crop production.
- **Natural Farming**: Utilizes various water sources, including atmospheric moisture and water found in the root zone, allowing for cultivation without relying solely on rainfall. It uses innovative practices like Pre-Monsoon Dry Sowing (PMDS) and systems that maintain green cover year-round.

Net Income

- **Conventional Agriculture**: Often leads to low net incomes, putting farmers in difficult situations.
- **Organic Farming**: Typically provides low to moderate positive incomes, influenced by price premiums for organic products.
- **Natural Farming**: Generally, results in higher net incomes due to the use of local, lightweight inputs, greater crop diversity and lower cultivation costs.

Consumer Health and Food Safety

- **Conventional Agriculture**: Can negatively affect health due to the use of harmful chemicals and the presence of residues on food.
- **Organic Farming**: Aims to improve consumer health by avoiding synthetic chemicals, offering foods that are free from residues.
- **Natural Farming**: Also focuses on consumer health, ensuring diverse, nutrient-rich foods that are free from harmful residues.

Impact on Natural Resources

- **Conventional Agriculture**: Harms natural resources, contributing to issues like desertification, land degradation and water pollution.
- **Organic Farming**: Helps reduce pollution in soil, water and air, leading to better resource management.
- **Natural Farming**: Achieves significant improvements in natural resources, enhancing soil health, biodiversity and conserving vital resources like water.

This analysis highlights the differences in methods and goals among the three systems, particularly in terms of sustainability, input use and seed diversity.

4. Scope and Importance of Natural Farming

Natural Farming is a valuable approach that focuses on working in harmony with nature to tackle pressing global challenges. By improving soil fertility and promoting environmental health, this method enhances agricultural productivity while also addressing climate change. Techniques used in Natural Farming, such as composting, crop rotation and agroforestry, help capture carbon in the soil, making it accessible for plants. This not only strengthens soil health but also creates more resilient ecosystems. Additionally, reducing the use of synthetic fertilizers and pesticides leads to safer food and cleaner water, addressing health issues related to agricultural runoff. From an economic perspective, Natural Farming can boost farmers' incomes by cutting down on input costs and increasing access to markets for sustainably produced goods. This approach can also generate job opportunities in rural communities, helping to keep young people in their hometowns and support local development. Overall, Natural Farming offers a sustainable solution to issues like food insecurity and rural hardship, fostering a fairer and more resilient agricultural system for the future. Its comprehensive approach is essential for creating a healthier planet.

5. Four pillars of Natural Farming

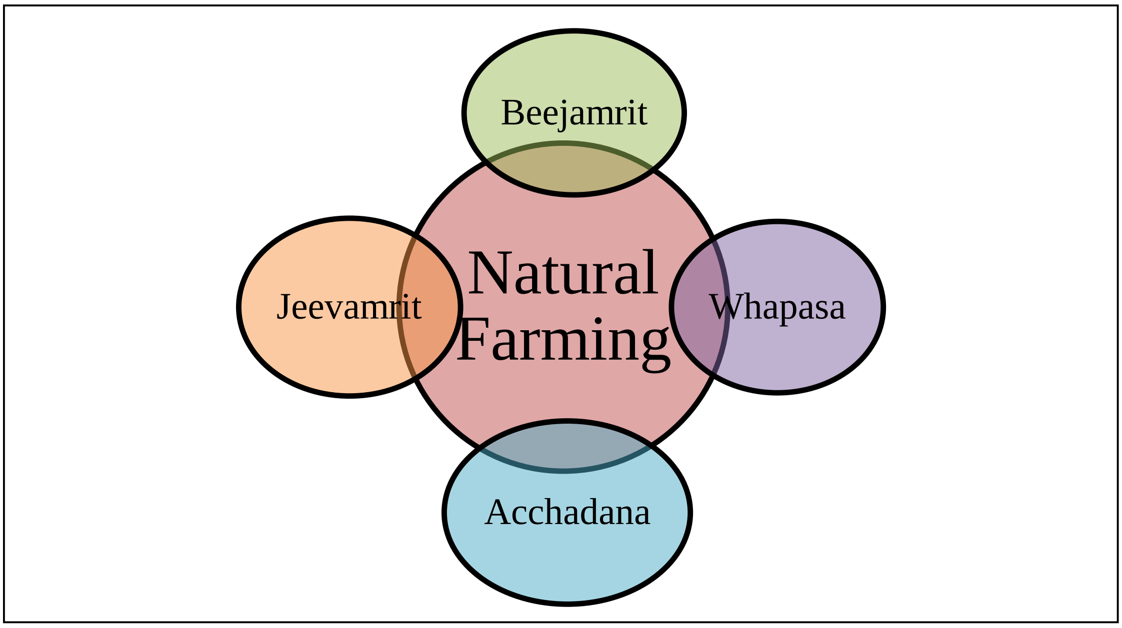
Jeevamrit, Beejamrit, Acchadana (mulching) and Whapasa are the four foundational pillars of Natural Farming.

- **Jeevamrit:** It is a microbial culture that enhances soil fertility and promotes healthy plant growth. The microbes found in jeevamrit aid in converting nutrients from an unavailable form to a soluble form when introduced into the soil. Additionally, they provide biological control by antagonizing pathogens[19]. Key microorganisms in this product include plant growth-promoting rhizobacteria (PGPR), phosphate-solubilizing bacteria (PSB), cyanobacteria, mycorrhizal fungi and nitrogen-fixing bacteria[20].
- **Beejamrit**: It is a bio-formulation used to treat seeds and seedlings. It also serves as a microbial culture, improving seed health and resilience. Research studies have demonstrated that inoculating with beejamrit can protect crops from harmful soil-borne pathogens and shield seedling roots from fungal infections, as well as seed and soil borne diseases. Additionally, beejamrit aids in the production of indole-3-acetic acid (IAA) and gibberellic acid (GA3)[21].
- **Acchadana (mulching):** It involves covering the soil to create a favorable micro-ecosystem that supports the growth of beneficial microorganisms and earthworms. Mulching can be classified into three types: Residue (Straw) mulch, soil mulch and live mulch. The use of cover crops, such as legumes, effectively reduces weed populations and enhances water infiltration capacity. These legumes' root nodules fix atmospheric nitrogen into the soil, providing an essential nitrogen supply for crops. Additionally, retaining these residues on the soil surface boosts microbial degradation processes and promotes nitrogen release through nitrification. Mulching also contributes organic matter to the soil, enriching it with various micro and macronutrients. Furthermore, it promotes seed germination without the need for soil plowing, lowers soil temperatures in extreme conditions and raises temperatures during winter. By minimizing evaporation, mulching conserves soil moisture, allowing water to be retained for a longer period.
- **Whapasa:** It refers to maintaining an ideal balance of moisture and air in the soil. It ensures that half of the space between soil particles is filled with moisture, while the other half remains air-filled. This balance is crucial for healthy plant growth, preventing excess water in the root zone. The primary concern is conserving water and applying it precisely based on the crop's water requirements. Applying water in alternate furrows can improve efficiency, as younger horizontal and vertical roots absorb more water and nutrients than older roots.

Together, these practices foster a thriving agricultural environment that supports sustainable farming.

1. Nutrient Management

Natural farming in India has great potential to use the abundant crop residues and straw available for recycling nutrients. By mixing these residues with soil microorganisms, the physical and chemical properties of the soil improve, which leads to better crop yields. Most of the farmers apply organic manures to the field, according to soil type, crop, season and farmer's prior knowledge and observation[22]. This approach focuses on creating a healthy microbial community that meets the nutritional needs of crops by accessing nutrients from the atmosphere, deeper soil layers and the breakdown of organic matter. Jeevamrit is important in this process because it transforms nutrients that plants cannot use into forms they can absorb, providing essential carbon, nitrogen, phosphorus, potassium and other micronutrients.



1.1 Preparations and Application of natural farming inputs

A. Jeevamrit

Preparation: To prepare jeevamrit, fill a barrel with 200 liters of water. Add 10 kg of cow dung and 5 to 10 liters of cow urine, then mix well with a wooden stick. Next, add 1 to 2 kg of jaggery and 1 to 2 kg of any pulse flour and mix everything thoroughly. Let the solution ferment for 3 to 4 days, shaking it three times a day.

Application: This mixture should be used every two weeks. It can be sprayed onto crops after being diluted or mixed with irrigation water. For fruit plants, it is recommended to apply it directly to each individual plant. It can be stored for up to 15 days.

Benefits: It provides a source of carbon, nitrogen, potassium, phosphorus and other essential nutrients. With over 700 million microorganisms, Jeevamrit helps convert nutrients from non-available forms to forms that plants can access when added to the soil.

B. Beejamrit

Preparation: To prepare beejamrit, take 5 kg of cow dung and wrap it in a cloth, securing it with tape. Hang the cloth in 20 liters of water for up to 12 hours. At the same time, mix 250 grams of lime in 1 liter of water and let it sit overnight. The next morning, squeeze the cow dung bundle into the water three times to ensure all the nutrients are released. Then, add a handful of soil to the water and stir well. Finally, mix in 5 liters of desi cow urine and the limewater and stir everything together thoroughly.

Application: To prepare seeds for planting, combine beejamrit with your crop seeds using your hands to ensure they are evenly coated. Let the seeds dry thoroughly before sowing. For leguminous seeds that have thin coatings, simply dip them quickly in beejamrit and allow them to dry.

Benefits: Beejamrit is a blend of various microflora, including several beneficial bacteria that promote plant growth by producing growth regulators. It effectively protects young roots from fungal infections. The beneficial microbes are expected to colonize the roots and leaves of germinating seeds, supporting healthy plant growth.

C. Ghanjeevamrit

Preparation: Ghanjeevamrit can be prepared by mixing 100 kg of indigenous cow dung (air dried for 4-5 days), add 1 kg of jaggery, 1 kg pulse flour, 3 litres of indigenous cow urine and add 250 g of soil from undisturbed bunds/ forest. After adding all the materials, this can be prepared like cakes.

Application: Before sowing, apply powdered Ghanjeevamrit at a rate of at least 2 quintals per acre.

Benefits: It serves as a biofertilizer, a catalytic agent and a promoter of microorganisms and earthworm activity in the soil. The formulations are good sources of beneficial microflora, making them effective plant growth promoters. Additionally, they increase the population of earthworms in the soil, which improve soil fertility and overall health.

D. Panchgavya

Peparation: Thoroughly combine cow dung and ghee, then let the mixture sit for three days. After this period, add 10 liters of cow urine and 10 liters of water, mixing well. Stir this blend every morning and evening for 15 days.Once completed, add the following ingredients: 2 liters of cow curd, 3 liters of tender coconut water, 3 liters of cow milk, 3 kg of jaggery and 12 ripe bananas. The Panchgavya preparation will be ready after 30 days.

Application: A 3% solution is effective for application, which means mixing 3 liters of Panchgavya with 100 liters of water.

Benefits: It helps in increasing the yield of fruits and vegetables.

E. Gudjal Amrit

Preparation: To prepare gudjal amrit, start by combining 3-5 kg of organic jaggery, 1 kg of gram flour, 10 kg of cow dung and 200 g of mustard oil in 200 liters of water. Once the ingredients are mixed, cover the container with a lid and place it in a shaded area for 24 hours. During this time, ensure that the mixture is well blended, particularly the cow dung and mustard oil, before incorporating them into the water mixture.

Application: The mixture can be combined with irrigation water or applied as a foliar spray on the leaves.

Benefits: It encourages the growth of soil microfauna and increases the availability of vital nutrients.

F. Sapta Dhanya Ankur Ark

Preparation: To prepare Sapta Dhanya Ankur Ark, gather the following ingredients: 100 g each of black till, green gram, black gram lentils, black-eyed peas, Indian brown lentil, wheat and brown chickpeas, along with 2 liters of cow urine and 200 liters of water. First, soak all the lentils in water for 24 hours. After soaking, drain the water and allow the lentils to sprout until they reach about 1 cm in length. Once sprouting is complete, make a paste from the lentils. Next, take 40 liters of water in a drum and add 2 liters of cow urine and the lentil paste. Mix well using a wooden rod, then cover the drum with a jute bag. Keep it in a shaded area for 2 hours.

Application: Solution should be sprayed after filtering.

Benefits: It acts as a growth promoter, enhancing the quality, texture and taste of fruits.

2. Plant diseases and Pest Management

7.1 Cultural Management: Using disease-free seeds and resistant varieties is one of the most effective preventive techniques in organic pest management. Additionally, maintaining biodiversity, implementing effective crop rotation and adopting a multiple cropping system can help keep insect populations below the economic threshold level (ETL). Planting insect-repellent crops, such as marigold, around the main crop serves as a useful strategy. Additionally, crops like gram and coriander can be planted within mustard fields to promote and protect natural enemies of harmful insects.

7.2 Mechanical Management: Effective mechanical methods for pest control include the removal of diseased plants and plant parts, as well as the collection of insect eggs and larvae. Other strategies involve installing scarecrows, using lighted insect traps, pheromone traps and sticky colored plates. Light traps are particularly effective for nocturnal insects, while sticky yellow traps are useful for monitoring and controlling pests like aphids and jassids, with one trap per 100 square meters being sufficient. The Vota T trap is specifically designed for brinjal shoot and fruit borer, as well as pin moth. Pheromone traps are commonly employed for managing most lepidopteran insects.

7.3 Biological Control: Biological control utilizes predatory, parasitic and pathogenic organisms to manage pests. Certain insects act as biological control agents by preying on specific plant pests and other micro-insects. Additionally, some parasitic organisms feed on harmful insects, helping to regulate their populations. For effective pest management in organic farming, applying agents such *as Trichogramma, Chelonus blackburni, Apantales* spp. and *Chrysoperla* should be done from 15 to 30 days after sowing.

7.3.1 Bio Pesticides: Bio-pesticides are derived from naturally occurring substances and include plant products such as alkaloids, terpenoids phenolics and other secondary chemicals. These substances are biologically active against insects and fungi. Common bio-insecticides include pyrethrum, nicotine, neem, margosa and rotenone. Many plants possess insecticidal properties and their extracts can be utilized in pest management. Some plant protection solutions can be made using a mixture of neem seeds, green chili, buttermilk, pepper powder and cow milk. [23]. The preparation methods for neemastra, agniastra and other insecticides are as follows:

A. **Neemastra Preparation:** For each acre, combine 100 liters of water, 5 liters of desi cow urine, 1 kg of cow dung and 5 kg of neem twigs. Mix the ingredients thoroughly and stir with a wooden stick in a clockwise direction. Allow the solution to sit in the shade for 48 hours, then filter it. This concentrated solution can be sprayed directly on the crops to effectively control sucking insects.

B. Agniastra Preparation: For each acre, combine 10 liters of desi cow urine, 5 kg of neem leaves (made into a chutney), 1 kg of tobacco powder, 500 grams of hot chili (made into a chutney) and 500 grams of desi garlic (made into a chutney). Boil the mixture over low heat. After boiling, let the solution sit in the shade for 48 hours, stirring it in the morning and evening. Once prepared, filter the solution through a cloth and store it for future use. To apply, dissolve 3 liters of the extract in 100 liters of water and spray it to target various insect pests. This solution can be safely stored for up to three months.

C. Brahmastra Preparation: Begin by crushing 5 kg of neem leaves in water, then add 10 liters of cow urine and 2 kg of cow dung. Stir the mixture intermittently for 24 hours, then filter and squeeze the extract. To prepare for spraying, dilute this solution by adding 40 times its volume in water. This preparation is highly effective against sucking pests and mealybugs. Brahmastra can be safely stored for up to six months.

D. Chili-Garlic Extract Preparation: To make the chili-garlic extract, grind together 1 kg of Adhatoda vasica leaves, 500 grams of garlic, 500 grams of red chili and 5 kg of neem leaves in 10 liters of cow urine. Boil the mixture until the volume is reduced by half. After boiling, filter the extract and store it in glass or plastic bottles. For use, dilute 2-3 liters of the extract in 100 liters of water. This solution is effective against pests such as gall midge, green leafhopper (GLH), thrips, whiteflies, semiloopers, fruit borers of brinjal and tomato, as well as tobacco caterpillars of soybean.

E. Cow Urine: Diluting cow urine with water in a 1:20 ratio for spraying on affected crops is not only helpful in managing pathogens and insects but also serves as a beneficial growth promoter for the crops.

7.3.2 Bio-Fungicides: In some regions of central India, long-fermented buttermilk (lassi or chhachh) is used as a bio-fungicide. Specifically, 3 liters of buttermilk that has been fermented for more than five days can be effective in managing pests like whiteflies and jassids, as well as serving as a fungicide.

8. Current Scenario of Natural Farming in India

Several states in India are actively promoting natural farming, including Andhra Pradesh, Gujarat, Himachal Pradesh, Odisha, Madhya Pradesh, Rajasthan, Uttar Pradesh and Tamil Nadu. Currently, over 1 million hectares of land are being cultivated using natural farming methods across the country. These initiatives reflect a growing commitment to sustainable agriculture and its benefits for both the environment and farmers. Natural farming is increasingly gaining traction in India, with around 409,000 hectares of land dedicated to this method as of 2023. The government has released a total fund of Rs 45.87 crore to support initiatives across eight states, including Tamil Nadu. This trend highlights a growing awareness of sustainable practices and the potential for improved agricultural outcomes.

According to a report by Niti Aayog, India has the potential to immediately increase the area dedicated to chemical-free farming to 15%, with the goal of reaching 30% by 2030. The report indicates that this shift would not jeopardize national food security, as any decrease in output and exports could be offset by savings from reduced fertilizer subsidies. The National Institute of Agricultural Extension Management (MANAGE) in Hyderabad serves as the nodal agency for promoting natural farming throughout India. The institute develops a significant network of natural farming experts by conducting numerous capacity-building programs for officials from various central and state agricultural departments, state agricultural universities, and private sector organizations. Additionally, MANAGE engages in various awareness campaigns aimed at educating farmers nationwide. In 2023, the Government of India introduced the National Mission on Natural Farming (NMNF) to encourage farmers to transition to chemical-free practices. The initiative aims to expand the adoption of natural farming across the country, targeting the cultivation of 10 million hectares by 2025.

9. Way Forward:

Natural Farming is a well-founded initiative by the Government of India, offering several significant advantages. By incorporating the following points into the process, the outcomes of this program can be greatly enhanced:

1. The integration of conservation agriculture with Natural Farming has considerable potential to alleviate the financial distress faced by farmers in advanced agricultural states like Punjab and Haryana.

2. Natural Farming presents ample opportunities to increase yield levels and improve net income for farmers, particularly in rain-fed agricultural systems.

References

- Foley JA, Ramankutty N, Brauman KA, Cassidy ES, Gerber JS, Johnston M *et al*. Solutions for a cultivated planet. Nature. 2011; 478 (7369):337-42.
- India Population Live (Worldometers, 2019); https://www.worldometers.info/ world-population/india-population/
- World Population Prospects, the 2012 Revision (UN Department of Economic and Social Affairs, 2013); https://go.nature.com/37N2olc
- Bruinsma, J. (ed.) World Agriculture: Towards 2015/2030. An FAO Perspective (Earthscan, 2003).
- Agoramoorthy, G. Can India meet the increasing food demand by 2020? Futures 40, 503–506 (2008).
- Smith, P. Delivering food security without increasing pressure on land. Glob. Food Secur. 2, 18–23 (2013).
- Subba Rao, A.,and Lenka, N.K.(2020).Developments on Soil Health Management in India as Mirrored through Sustained Researches and Policy Interventions. Indian J. Fert. 16, 1230–1242.
- Çelik, İ., Günal, H., Acir, N., Barut, Z. B. and Budak, M. (2021). Soil Quality Assessment to Compare Tillage Systems in Cukurova Plain, Turkey. Soil Tillage Res. 208, 104892. doi:10.1016/j.still.2020.104892.
- Janků, J., Kosánová, M., Kozák, J., Herza, T., Jehlička, J., Maitah, M., et al. (2022). Using of Soil Quality Indicators to Assess Their Production and Ecological Functions. Soil Water Res. 17, 45–58. doi:10.17221/146/2021-SWR
- Sanhati Collective Farmer Suicides in India: A Policy-induced Disaster of Epic Proportions http://sanhati.com/excerpted/4504/ (2012).
- Patel, V. et al. Suicide mortality in India: a nationally representative survey. Lancet 379, 2343–2351 (2012).
- Kennedy, J. & King, L. The political economy of farmers' suicides in India: indebted cash-crop farmers with marginal landholdings explain state-level variation in suicide rates. Glob. Health 10, 16 (2014).
- Abhilash, P. C. & Singh, N. Pesticide use and application: an Indian scenario. J. Hazard. Mater. 165, 1–12 (2009).
- Kumari, S. & Sharma, H. The impact of pesticides on farmer's health: a case study of fruit bowl

of Himachal Pradesh. Int. J. Sci. Res. 3, 144–148 (2012).

- Fukuoka M (1978) The one straw revolution. Rodale Press, Emmaus, PA, USA.
- Andow DA, Hidaka K (1998) Yield loss in conventional and natural rice farming systems. Agri Eco and Envi 74: 137–155 70: 151-158.
- Neera P, Katano M, Hasegawa T (1992) Rice culture under Nature Farming in Japan. Proc Fac Agric KyushuTokai Univ ll: 67-74.
- Palekar S. Undated. The philosophy of spiritual farming: zero budget natural farming.Revised fourth edition. Zero Budget Natural Farming Research, Development & Extension Movement, Amravati, Maharashtra India.
- Glick, B.R., & Abd Bashan, Y. (1997). Genetic manipulation of plant growth promoting bacteria to enhance biocontrol of phytopathogens. Biotech Adv., 15, 353-378.
- Chen, C., Bauske, E.M., Musson, G., & Rodríguez, K.R. (1995). Biological control of Fusarium wilt on cotton by use of endophytic bacteria Biological Control, 5, 83-91.
- Sreenivasa, M.N., Naik, N.M., & Bhat, S.N. (2010). Beejamruth: A source for beneficial bacteria. Karnataka J Agric Sci., 17, 72-77.
- Niassy, S., Karamoko Diarra, Youga Niang, Seydou Niang and Hans-Rudolf Pfeifer. "Effect of organic fertilizers on the susceptibility of tomato Lycopersicon esculentum: Solanaceae to Helicoverpa armigera Lepidoptera: Noctuidae in the Niayes area Senegal." (2010): 708-712.
- Palekar, S. (2016) Zero Budget Natural Farming. http://palekarzerobudgetspiritual farming.org

EMPOWERING PLANT PROTECTION WITH DRONE TECHNOLOGY: A PATH TO SMARTER AGRICULTURE

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ABSTRACT

Drones play a vital role in precision agriculture by performing various farming operations aimed at maximizing crop yield while minimizing resource input. Among the major threats to agricultural productivity, plant diseases stand out as a primary cause of yield loss and pose significant risks to global food security. Unmanned Aerial Systems (UAS), equipped with advanced sensors and high-resolution imaging systems, facilitate real-time monitoring, rapid data acquisition, and early detection of plant diseases. These capabilities enable timely interventions and the implementation of effective disease management strategies. The data collected by drones can be analyzed using computational tools, including deep learning algorithms and advanced analytics, to detect disease patterns and quantify disease severity. Furthermore, integrating this data with meteorological information supports the development of region-specific disease forecasting models, enhancing predictive capabilities and proactive disease control.

Keywords: Drone, unmanned aerial system, disease detection, pesticide spraying

INTRODUCTION:

The rapid growth of the global population presents a significant challenge in ensuring adequate food production. Enhancing agricultural output is a complex and multifactorial objective, influenced by advancements in technology, improvements in infrastructure, supportive policies, and the adoption of sustainable agricultural practices. The integration of modern technologies into agriculture is essential to meet the rising food demands. However, crop productivity is adversely affected by a range of biotic and abiotic stressors, including weeds, pests, plant diseases, unfavorable climatic conditions, and nutrient deficiencies. Among these, plant diseases are one of the most detrimental factors, often causing substantial yield losses and compromising both the quality and quantity of agricultural produce. They pose a critical threat to global food security. Consequently, the implementation of efficient monitoring systems, early disease detection, and timely intervention is crucial to limit disease spread, enhance crop protection, and reduce the reliance on chemical pesticides.

Conventional methods for plant disease detection primarily rely on visual inspection of symptomatic plants, often requiring the expertise of trained personnel. These methods are typically time-consuming, labor-intensive, costly, and impractical for application across large-scale agricultural fields. Therefore, the development and deployment of rapid, accurate, and scalable disease detection technologies are critical for effective crop management. In recent years, drone technology has emerged as a transformative tool in the agricultural sector, facilitating a range of operations including crop monitoring, pesticide application, fertilization, seeding, irrigation management, and even livestock surveillance. Unmanned Aerial Vehicles (UAVs) equipped with high-resolution cameras and multispectral sensors can capture detailed aerial imagery of crop fields, providing real-time and precise assessments of crop health. These aerial images enable early detection of plant diseases by identifying stress indicators that are not easily visible to the naked eye. Furthermore, drones integrated with advanced spraying systems can be employed for targeted pesticide application, thereby reducing both the cost and volume of chemical usage (Ahirwar et al., 2019).

In recent years, deep learning algorithms have emerged as a highly effective approach for enhancing computer vision-based systems used in automated crop disease monitoring. These algorithms are capable of autonomously extracting relevant features from input data without the need for manual intervention, thereby providing critical insights that support informed decision-making by farmers. This not only contributes to reducing crop treatment costs but also helps in improving overall agricultural productivity. The integration of high-resolution imaging systems such as multispectral or hyper spectral sensors with deep learning techniques presents a promising solution for the early and accurate detection of plant diseases (Bouguettaya et al., 2023).

DRONE (Dynamic Remotely Operated Navigation Equipment)

A drone, also referred to as an Unmanned Aerial System (UAS) or Unmanned Aerial Vehicle (UAV), is an aerial platform that can be operated remotely by a ground-based human pilot or can function autonomously through pre-programmed flight paths. These autonomous operations are managed by an onboard embedded system integrated with various sensors and Global Positioning System (GPS) technology, enabling precise navigation and real-time data acquisition.

Types of Drones:

While various types of drones are utilized across multiple industries for commercial applications, in the agricultural sector, two primary categories of drones are predominantly employed to perform a range of farming operations.

1. **Fixed wing drones:**

   Fixed-wing drones, characterized by their rigid, non-rotating wings similar to conventional airplanes, are generally more robust and durable than multi-rotor drones. These drones achieve sustained flight by utilizing the aerodynamic lift generated by their fixed wings, allowing them to operate efficiently at higher speeds and for extended durations. Their structural resilience enables them to perform reliably under harsh weather conditions. However, fixed-wing drones are typically more expensive and require larger spaces for takeoff and landing due to their design constraints. They often depend on runways or launch systems for takeoff and employ controlled descent mechanisms for landing. Capable of being programmed for fully autonomous flights, fixed-wing drones are particularly well-suited for applications such as large-scale crop monitoring, field mapping, and transporting heavier payloads over long distances.

2. **Multi-rotor drones:**

   Multi-rotor drones also known as multi-copters are unmanned aerial vehicles that utilize multiple rotors to achieve controlled flight. These drones are more popular for their versatility, maneuverability. They are easy to flight and lot cheaper than fixed wing drones. Multi-rotors drone not only used for aerial photography and videography but their design allows them to be used for the application of crop spraying and seeding operations in agriculture. Their design also allows them for installation of high resolution cameras and various sensors to collect real time information about the crop health and growth. Multi-rotor drones have varied payload capacities depending on their size, design and rotor configuration. Depending on the numbers of rotors on the wing of drones multirotor drones can be categorized as; tricopter (3 rotos), quadcopter (4 rotors), hexacopter (6 rotors) and octocopter (8 rotors). The quadcopter and hexacopter drones commonly used for crop spraying with agrochemicals. This drones has short flight time as compared to fixed wing drones.

Fixed wing drone

Multi-rotor drone

APPLICATION OF DRONES IN PLANT PROTECTION:

Drones have emerged as valuable tools in modern agriculture, particularly for plant protection and crop management. They provide efficient, precise, and targeted solutions for the monitoring and control of pests and plant diseases. The following are key applications of drone technology in the domain of plant protection:

1. **Plant disease detection:**

Drones equipped with high-resolution cameras or multispectral sensors can capture detailed aerial images of crop plants. Multispectral sensors detect variations in the wavelengths of light reflected by vegetation. Healthy leaves contain higher concentrations of chlorophyll, which results in greater reflection of near-infrared (NIR) light. Conversely, infected, stressed, or senescent leaves exhibit reduced chlorophyll content, leading to increased absorption and decreased reflection of NIR light. These spectral variations, detected by multispectral or hyperspectral sensors, provide precise and reliable information regarding crop health.

One widely used imaging metric for assessing vegetation health is the Normalized Difference Vegetation Index (NDVI). NDVI is based on the principle that the spongy mesophyll layer of healthy leaves reflects more green and NIR light compared to stressed or damaged leaves. When leaves are stressed or diseased, the mesophyll structure deteriorates, resulting in decreased NIR reflectance and increased absorption. Utilizing NDVI, farmers can effectively evaluate crop health and detect the presence of plant disease infections.

2. **Crop damage assessment:**

Drones equipped with multispectral or hyperspectral sensors offer highly accurate data for assessing crop health, monitoring growth stages, and evaluating crop loss. These systems provide real-time information throughout the entire crop development cycle, enabling farmers to make timely decisions and implement effective plant disease management strategies, thereby optimizing yield while minimizing resource use.

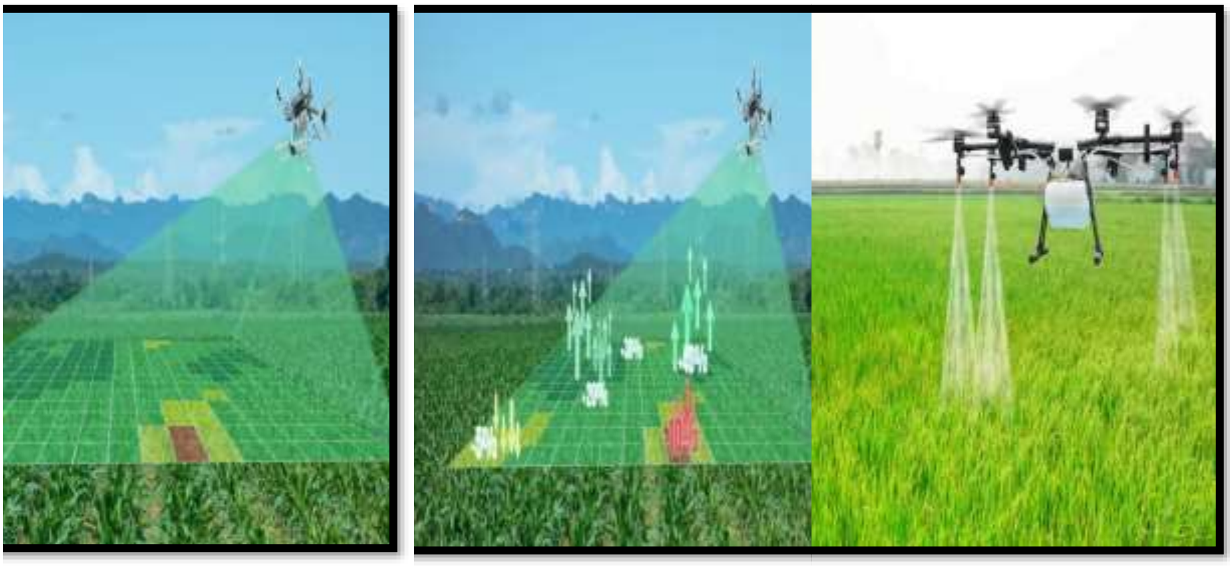
Multispectral and hyperspectral imaging capture variations in light reflectance that correspond to the biophysical and biochemical changes in crops induced by disease infection. Additionally, thermographic sensors measure temperature variations on leaf surfaces and crop canopies, facilitating the detection of latent infections that are not visible through conventional means.

The data collected allows for the analysis of disease patterns and progression rates within fields. When integrated with meteorological data, these insights support the development of region-specific or continent-wide disease prediction models. The interpretation of such complex datasets relies on advanced software tools utilizing deep learning and machine learning algorithms to classify plant diseases accurately and generate actionable information for crop management.

3. Precision crop spraying:

Drones equipped with advanced spraying systems enable precise and efficient pesticide application in agricultural fields. The site-specific targeting capability of drone spraying reduces pesticide volume and associated costs, while also minimizing environmental impact. This technology allows for rapid coverage of large farm areas, significantly reducing the time required for spraying operations. Moreover, drone-based spraying mitigates direct exposure of farmers and laborers to hazardous chemicals, enhancing safety compared to traditional manual spraying methods.

Utilizing ultra-low volume (ULV) spraying technology, drones decrease water consumption by up to 90% relative to conventional approaches, thereby conserving water resources. Drone spraying is particularly advantageous in challenging terrains, such as hilly or muddy areas, where manual application is impractical. The ability of drones to dispense pesticides as fine chemical mists with small droplet sizes facilitates rapid penetration through the plant cuticle, improving efficacy and reducing chemical overuse. Given current labor shortages in agriculture, drone-based pesticide application represents an efficient and scalable alternative for large-scale crop spraying.



Disease detection through drone | **Crop monitoring through drone** | **Crop spraying with drone**

BENEFITS OF DRONES IN AGRICULTURE:

1. Safety and environmental benefits:

Drones can be controlled from distances or from farm bund by well trained drone pilot so this eliminate or minimize the direct contact of farmers or farm labours with hazardous chemicals and risk of accidents while conducting farming operations. Additionally the targeted application of pesticide reduced chemical usage and minimizing environment impact and promoting sustainable farming practices.

2. **Time and cost saving:**

The automated flight capabilities of drones enable significant time savings and reduce labor requirements in agricultural operations. Farmers can efficiently manage the preparation of pesticide mixtures and water for drone-assisted crop spraying, which contrasts with the more labor-intensive conventional methods. Drones are capable of covering extensive areas within a short timeframe while simultaneously providing real-time data on crop health. This timely information facilitates prompt decision-making and intervention, ultimately enhancing crop productivity. Drone utilizes ultra low volume spraying technology which minimizes water use upto 90% as compared to conventional method. Due to high atomization drone deliver very fine spray of chemicals as chemical for which save 30% pesticide.

3. **Lower maintenance cost:**

Agricultural drones are constructed using high-quality, durable materials, resulting in an extended operational lifespan and reduced maintenance requirements. Component replacement is straightforward, and manufacturers typically offer timely servicing and support as needed.

LIMITATIONS OF DRONE IN AGRICULTURE:

Despite their numerous advantages in agricultural applications, drones possess certain limitations that must be acknowledged. The following are some key constraints:

1. **Short flight time and limited payload capacity:**

One of the primary limitations of drones in agricultural applications is their relatively short flight duration, typically ranging from 20 to 60 minutes. This is largely due to the additional payload from components such as spraying systems, high-resolution cameras, or advanced sensors. As a result, drones can only cover a limited area per charge, necessitating frequent recharging or battery replacement to survey or treat larger fields. This constraint poses a challenge for operations on large-scale farms.

2. **Cost of drones:**

Drones utilized for agricultural surveillance, particularly fixed-wing models, tend to be relatively expensive. The high initial investment cost can be a significant barrier for smallholder farmers. This cost is primarily influenced by factors such as payload capacity, flight duration, operational range, and the integration of advanced technologies, including high-resolution imaging systems, multispectral or hyperspectral sensors, and specialized spraying or seeding equipment.

3. **Connectivity:**

In rural regions, the lack of reliable internet connectivity poses a challenge to the effective use of drone technology. Under such conditions, farmers may be required to invest in establishing internet infrastructure to support data transmission, real-time monitoring, and remote drone operations.

4. **.Weather dependence:**

Weather conditions play a critical role in the operational efficiency of drones. Adverse environmental factors such as heavy rainfall, strong winds, or extreme temperatures can compromise flight stability and safety. Therefore, drone deployment is generally not recommended under such conditions, as they may limit flight capability and data acquisition accuracy.

5. **Regulatory restrictions:**

Regulatory frameworks governing drone operations typically impose altitude restrictions and mandate line-of-sight operation. These regulatory constraints can limit the operational flexibility of drones and necessitate additional planning and coordination to ensure compliance during agricultural activities.

6. **Technical expertise and training:**

Operating agricultural drones requires the user to undergo certified drone pilot training. Additionally, the interpretation and analysis of acquired data demand specialized technical skills in data processing and geospatial analysis. Consequently, farmers must either acquire the necessary expertise or employ trained professionals to manage drone operations and perform data analysis effectively.

7. **Privacy invasion:**

Drones equipped with high-resolution cameras pose potential risks related to privacy infringement. Unauthorized surveillance or the capture of aerial imagery without consent may violate individuals' privacy rights and could lead to the unlawful collection or dissemination of sensitive or confidential information.

GENERAL LAWS FOR DRONE OPERATION IN INDIA

The laws and regulations regarding drones in India are governed by Directorate General of Civil Aviation (DGCA), which is the regulatory body for civil aviation.

1. **Categories of Drones:**

Based on the size and maximum takeoff weight drone can be divided into five categories: nano, mini, small, medium and large. Each category of drone has different restriction for flying operations.

2. **Registrations:**

All categories of drones except nano (less than 250 gm) must to be registered and issued Unique Identification Number from DGCA. Detailed information about Drone and user must be providing to DGCA.

3. **Operator permit:**

For commercial drone operation permission is required and issued from DGCA. Drone user must complete drone pilot training and issue license from authentic institution.

4. **No fly zones:**

These include:

1. 5 km near airport or area where aircraft is operating.
2. Highly sensitive areas like government or military facilities.
3. National park or wildlife sanctuaries.
4. Over crowded or large populated areas.

5. Flight restrictions:

Drone cannot be flown more than 400 ft. vertically. Drone cannot be flown during adverse weather condition and night time; it is advisable to fly during good weather condition and daylight period.

6. Visual line of sight:

Drone operator required to maintain visual line of sight with drones during the entire flight operation. This means that drone should be visible during fly operation to drone pilot.

7. Drone operation permission:

Commercial drone operation requires additional permissions, clearance and compliance with specific guidelines. Permission is required for every flying operation from nearest police station or security institute.

CONCLUSION:

In modern agriculture, drones are increasingly utilized to perform a variety of farming operations and are recognized as highly effective tools for rapid, accurate, and non-destructive detection of field-related issues. By delivering real-time data on crop health, drone technology facilitates the early identification of plant diseases, enabling timely intervention and improved crop management. Given the challenges posed by labour shortages and the limited availability of technically skilled personnel, drones represent an optimal solution for implementing precision agriculture practices. Therefore, it is imperative for government authorities to formulate farmer-centric policies, legal frameworks, and strategic initiatives, including the development of supporting infrastructure and the establishment of training centers to build human resource capacity in agricultural drone technology.

REFERENCES:

- Ahirwar, S, Swarnkar R, Bhukya S. and Namwade G. 2019. Application of Drone in Agriculture. *Int. J. Curr. Micro biol. App. Sci.* 8(01): 2500-2505.
- Bouguettaya, A., Zarzour, H., Kechida, A. and Taberkit, A. M. (2023) Survey on deep learning-based identification of plant and crop diseases from UAV-based aerial images. *Cluster Computing* 26:1297–1317.
- Ramanjaneyulu A V, Sainath N, Swetha D, Ramprasad B, Varma, Uma Reddy, Jagadeeshwar, R and Nagarjuna T. 2021. Can Drones Reduce Plant Protection Costs in Agriculture– An Experience Based Analysis. *Chron. Bio.Manag.*, **5**(4):161-165.
- Rejeb A, Abdollahi A, Rejeb K, and Treiblmaier H. 2022. Drones in agriculture: A review and bibliometric analysis. *Computers and Electronics in Agriculture*, 198, 107017.

CONTRACT FARMING IN AGRICULTURE

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Contract farming can be defined as agricultural production carried out according to an agreement between a buyer and farmers, which establishes conditions for the production and marketing of a farm product or products. Typically, the farmer agrees to provide agreed quantities of a specific agricultural product. These should meet the quality standards of the purchaser and be supplied at the time determined by the purchaser. In turn, the buyer commits to purchase the product and, in some cases, to support production through, for example, the supply of farm inputs, land preparation and the provision of technical advice.

Objectives

Contract Farming works towards:

- Reducing the load on the central and state level procurement systems.
- Increasing private sector investment in agriculture.
- Bringing the market focus of crop selection by Indian farmers.
- Generating a steady source of income at the individual farmer level.
- Promoting processing and value addition.
- Generating gainful employment in rural communities.
- Reducing migration from rural to urban areas.
- Promoting rural self-reliance in general by pooling locally available resources and expertise to meet new challenges.

Contract farming business models:

- **Informal model** - This model is the most transient and speculative of all contract farming models, with a risk of default by both the promoter and the farmer" (van Gent, n.d., p.5). However, this depends on the situation: interdependence of contract parties or long-term trustful relationships may reduce the risk of opportunistic behaviour. Special features of this CF model are:
  - Small firms conclude simple, informal seasonal production contracts with smallholders.
  - The success often depends on the availability and quality of external extension services.
  - Embedded services, if at all provided, are limited to the delivery of basic inputs, occasionally on credit; advice is usually limited to grading and quality control.
  - Typical products: requiring minimal processing/ packaging, vertical coordination,

  - e.g. fresh fruit/ vegetables for local markets, sometimes also staple crops.
- **Intermediary model** - In this model, the buyer subcontracts an intermediary (collector, aggregator or farmer organisation) who formally or informally contracts farmers (combination of the centralised/ informal models). Special characteristics of this CF model are:
  - The intermediary provides embedded services (usu- ally passing through services provided by buyers against service charges) and purchases the crop.
  - This model can work, if well-designed and if incentive-structures are adequate and control mechanisms are in place.
  - This model can bear disadvantages for vertical coordination and for providing incentives to farmers (buyers may lose control of production processes, quality assurance and regularity of supplies; farmers may not benefit from technology transfer; there is also a risk of price distortion and reduced incomes for farmers).
- **Multipartite model** - This model can develop from the centralised or nucleus estate models, e.g. following the privatisation of para- statals. It involves various organisations such as govern- mental statutory bodies alongside private companies and sometimes financial institutions. Special features:
  - This model may feature as joint ventures of parastatals/ community companies with domestic/ foreign investors for processing.
  - The vertical coordination depends on the discretion of the firm. Due attention has to be paid to possible political interferences.
  - This model may also feature as farm-firm arrangement complemented by agreements with 3rd party service providers (e.g. extension, training, credits, inputs, logistics).
  - Separate organisations (e.g. cooperatives) may organise farmers and provide embedded services (e.g. credits, extension, marketing, sometimes also processing).
  - This model may involve equity share schemes for producers.
- **Centralized model** - In this model, the buyers' involvement may vary from minimal input provision (e.g. specific varieties) to control of most production aspects (e.g. from land preparation to harvesting). This is the most common CF model, which can be characterised as follows:
  - The buyer sources products from and provides services to large numbers of small, medium or large farmers.
  - The relation/ coordination between farmers and contractor is strictly vertically organised.

- The quantities (quota), qualities and delivery conditions are determined at the beginning of the season.
- The production and harvesting processes and qualities are tightly controlled, sometimes directly implemented by the buyer's staff.
- Typical products: large volumes of uniform quality usually for processing, e.g. sugar cane, tobacco, tea, coffee, cotton, tree crops, vegetables, dairy, poultry.

- **Nucleus estate model** - In this model, the buyer sources both from own estates/ plantations and from contracted farmers. The estate system involves significant investments by the buyer into land, machines, staff and management. This CF model can be characterised as follows:
  - The nucleus estate usually guarantees supplies to assure cost-efficient utilisation of installed processing capacities and to satisfy firm sales obligations respectively.
  - In some cases, the nucleus estate is used for research, breeding or piloting and demonstration purposes and/ or as collection point.
  - The farmers are at times called 'satellite farmers' illustrating their link to the nucleus farm. This model was in the past often used for state owned farms that re-allocated land to former workers. It is nowadays also used by the private sector as one type of CF. This model is often referred to as "outgrower model".
  - Typical products: perennials

Advantages:

Contract farming is looking towards the benefits both for the farm-producers as well as to the agro-processing firms.

Producer/farmer

- Makes small scale farming competitive - small farmers can access technology, credit, marketing channels and information while lowering transaction costs
- Assured market for their produce at their doorsteps, reducing marketing and transaction costs
- It reduces the risk of production, price and marketing costs.
- Contract farming can open up new markets which would otherwise be unavailable to small farmers.
- It also ensures higher production of better quality, financial support in cash and /or kind and technical guidance to the farmers.
- In case of agri-processing level, it ensures consistent supply of agricultural produce with quality, at right time and lesser cost.

Agri-based firms

- Optimally utilize their installed capacity, infrastructure and manpower, and respond to food safety and quality concerns of the consumers.
- Make direct private investment in agricultural activities.
- The price fixation is done by the negotiation between the producers and firms.
- The farmers enter into contract production with an assured price under term and conditions.

Challenges:

- Contract farming arrangements are often criticized for being biased in favor of firms or large farmers, while exploiting the poor bargaining power of small farmers.
- Problems faced by growers like undue quality cut on produce by firms, delayed deliveries at the factory, delayed payments, low price and pest attack on the contract crop which raised the cost of production.
- Contracting agreements are often verbal or informal in nature and even written contracts often do not provide the legal protection in India that may be observed in other countries. Lack of enforceability of contractual provisions can result in breach of contracts by either party.
- Single Buyer – Multiple Sellers (Monopsony).
- Adverse gender effects - Women have less access to contract farming than men.

ICT, FARMER PRODUCER ORGANIZATIONS, AND COMMUNITY-LED INNOVATIONS: PATHWAYS TO SUSTAINABLE AGRICULTURAL TRANSFORMATION

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ABSTRACT

Agriculture in developing economies faces multiple challenges, including fragmented landholdings, limited access to markets, lack of credit, and vulnerability to climate change. In this context, the integration of Information and Communication Technologies (ICTs), Farmer Producer Organizations (FPOs), and community-led innovations has emerged as a transformative pathway to enhance productivity, market access, and rural livelihood security. ICT tools provide real-time weather advisories, digital credit access, precision agriculture, and e-marketing, bridging critical information asymmetries. FPOs, as collective institutions, enable smallholders to achieve economies of scale in procurement, value addition, and marketing, while community-based innovations ensure contextualized, socially acceptable, and sustainable practices. Together, these drivers foster inclusivity, strengthen institutional capacity, and align with the Sustainable Development Goals (SDG 2: Zero Hunger, SDG 8: Decent Work and Economic Growth, SDG 13: Climate Action). This chapter reviews global and Indian experiences, highlighting statistical evidence—such as the registration of 18,000+ FPOs in India by 2024 covering 3.2 million farmers—and explores case studies where ICT platforms and grassroots innovations have transformed farming systems. The discussion emphasizes opportunities, bottlenecks, and policy frameworks to mainstream ICT, FPOs, and community innovations into national agricultural strategies.

Keywords: ICT in agriculture, Farmer Producer Organizations, community innovations, food security, sustainable agriculture, digital farming, SDGs

1. Introduction

Agriculture remains the backbone of rural livelihoods, with over 2.5 billion people globally depending on farming as their primary source of income (FAO, 2022). However, challenges such as climate variability, declining soil fertility, and market inefficiencies limit its potential. In India, where nearly **86% of farmers are smallholders**, fragmented landholdings reduce economies of scale and bargaining power. Farmer Producer Organizations (FPOs), ICT tools, and community-led innovations have emerged as complementary approaches to address these constraints. ICT enables knowledge dissemination and digital solutions, FPOs build collective strength, and community innovations ensure participatory adoption. This triad represents a powerful ecosystem for rural transformation and food system resilience.

- Financial sustainability of FPOs due to weak governance structures.
- Exclusion of women and marginalized groups from leadership roles.
- Fragmented policy landscape with overlapping schemes.

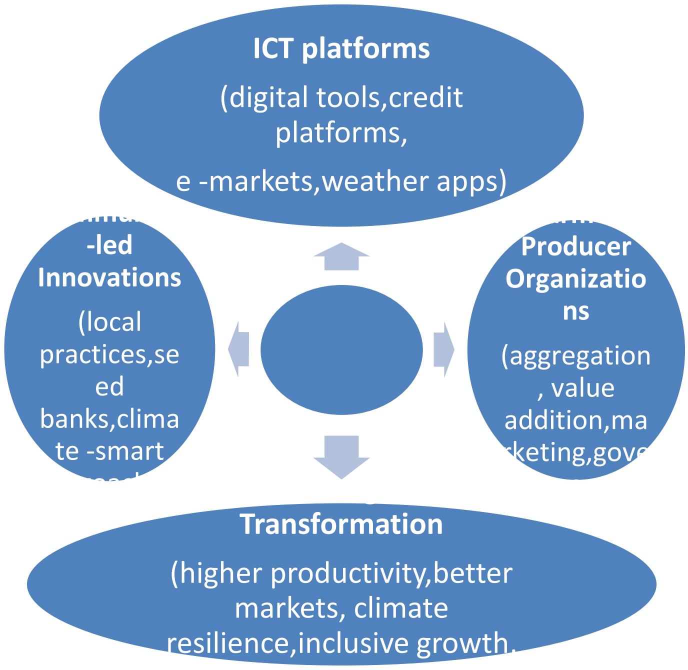
2. Conceptual Framework

The interaction of ICT tools, FPOs, and community-led innovations forms a triangular ecosystem driving sustainable agriculture.

- **ICT as an Enabler:** Provides access to real-time data on weather, soil health, crop advisories, and digital markets. This reduces information asymmetry, enhances decision-making, and improves risk management.
- **FPOs as Aggregators:** They strengthen farmer collective action, enable economies of scale in input procurement, value chain integration, and improve **bargaining power** in markets.
- **Community Innovations as Localized Solutions:** Farmers and local institutions generate context-specific practices (e.g., low-cost irrigation systems, traditional pest control, community seed banks) that ensure adoption and long-term sustainability.

Together, these three elements address the technical, economic, and social dimensions of agriculture.

Conceptual Model:



This triangular relationship creates **synergy**: ICT strengthens FPO management and marketing, FPOs help scale up community innovations, and community knowledge enhances ICT adoption and trust.

3. Literature Review

Studies show that ICT reduces transaction costs and improves farm-level decision-making (World Bank, 2021). FPOs are recognized as instruments for farmer empowerment, with evidence from Amul (dairy cooperatives) to state-led FPO promotion under SFAC (Small Farmers' Agribusiness Consortium). Community-led initiatives, such as self-help groups (SHGs) in Kerala or women-led seed networks in Odisha, highlight the role of social capital in agricultural development. Despite progress, gaps remain in scaling digital literacy, ensuring financial sustainability of FPOs, and integrating grassroots innovations into formal policy frameworks

4. Policy and Institutional Innovations

4.1 Government of India Initiatives

1. **Digital Agriculture Mission (2021–25):**
    - Promotes AI, IoT, blockchain, and GIS mapping for farming.
    - Pilot projects include drone-based spraying and soil digital mapping.
2. **10,000 FPO Formation Scheme (2020):**
    - Target: 10,000 new FPOs by 2027, with ₹6,865 crore budget.
    - As of 2024, 18,000 FPOs registered, covering 3.2 million farmers.
3. **e-NAM (National Agriculture Market):**
    - Integrates 1,260+ mandis across 22 states.
    - By 2023, ₹2.05 lakh crore trade transacted digitally.
4. **PM-KISAN and KCC Digitalization:**
    - 118 million farmers receive direct income support.
    - Kisan Credit Cards are linked with mobile apps for credit access.

4.2 Institutional Innovations

- **SFAC (Small Farmers Agribusiness Consortium):** Provides equity grants, credit guarantees, and mentoring for FPOs.
- **NABARD & NABSANRAKSHAN:** Extends credit, capacity building, and risk mitigation services for FPOs.
- **Private Sector Models:**

- AgroStar (Maharashtra): Mobile-based input advisory.
- Ninjacart (Karnataka): Digital platform linking farmers directly with retailers.

- **NGO Models:**
    - PRADAN & SEWA*:* Promoting women-centric producer groups and digital training.

Together, these innovations institutionalize collective action and embed ICT solutions in rural development.

5. Community-Led Innovations and Case Studies

Community-driven approaches ensure ownership, trust, and sustainability. Unlike top-down interventions, they integrate local knowledge with modern science.

5.1 Case Studies

1. **Odisha – Community Seed Banks**
    - Farmers organized through NGOs to preserve indigenous rice varieties.
    - Result: Improved climate resilience (drought- and flood-tolerant varieties).
    - By 2023, over 250 seed banks were established, reducing seed dependency on external markets.
2. **Maharashtra – Onion FPO Success**
    - FPOs aggregated produce and directly linked with exporters in Dubai and Qatar.
    - Farmers' income increased by 20–30%.
    - Adoption of ICT platforms (WhatsApp, digital payment gateways) streamlined operations.
3. **Bihar – Women SHGs and Organic Farming**
    - Women-led SHGs promoted low-cost organic pest management using neem and cow dung.
    - Supported by JEEVIKA program, scaling organic vegetable clusters.
    - Households saw 25% higher net returns and improved household nutrition.
4. **Kenya – Digital Advisory Platforms (International Example)**
    - M-Farm App: Provides real-time price information, reducing middlemen exploitation.
    - Over 1 million farmers reached, with evidence of 10–15% higher farm-gate prices.

5.2 Comparative Insights

- **India:** Strength lies in FPO movement and government schemes.
- **Africa:** Strong uptake of mobile-based ICT solutions due to high mobile penetration.
- **Global Lesson:** Blending digital tools, collective institutions, and local innovations works better than standalone interventions.

6.Key Takeaways from Expanded Sections

- **Conceptual Framework** highlights ICT–FPO–Community synergy.
- **Policy & Institutional Innovations** show strong government support but also reliance on NGOs and private startups.

Case Studies demonstrate tangible benefits—from higher incomes to climate resilience.

7. Challenges and Bottlenecks

- Limited digital literacy among rural farmers (only 38% of rural households had internet access in 2023, NFHS-5).
- Financial sustainability of FPOs due to weak governance structures.
- Exclusion of women and marginalized groups from leadership roles.
- Fragmented policy landscape with overlapping schemes.

8. Future Outlook and Opportunities

- **ICT Integration:** Leveraging AI, drones, and big data for precision agriculture.
- **Institutional Strengthening:** Capacity building for FPO leaders, gender-inclusive governance.
- **Community Empowerment:** Scaling participatory innovations through NGO–government partnerships.
- **Policy Linkages:** Aligning ICT and FPO schemes with SDGs and carbon markets.

By 2030, synergizing ICT, FPOs, and community approaches can ensure inclusive, climate-resilient, and market-driven agriculture.

9. Conclusion

ICT, FPOs, and community-led innovations collectively offer a robust pathway to sustainable agricultural transformation. Their integration addresses information asymmetry, market inefficiency, and climate vulnerability while ensuring inclusivity. However, success depends on coherent policies, digital infrastructure, and participatory governance. Strengthening this triad can enable farming communities not just to survive but to thrive in the face of 21st-century challenges.

References

- FAO (2022). *The State of Food and Agriculture.* Rome: FAO.
- SFAC (2024). *Annual Report on Farmer Producer Organizations.* Ministry of Agriculture, Government of India.
- World Bank (2021). *Digital Agriculture: Transforming Agricultural Systems.* Washington, DC: World Bank.
- NFHS-5 (2023). *National Family Health Survey – Rural Digital Access Report.*

CHALLENGES AND STRATEGIES FOR IMPROVING NATURAL FARMING IN INDIA

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ABSTRACT

Natural Farming (NF) is understood as a chemical free farming practice involving livestock integrated natural farming methods and diversified crop systems rooted in the Indian traditional knowledge and also it is location specific & follows the agro-ecological principles and is rooted in the local knowledge. Practices such as use of natural inputs, mulching, green cover etc increases the soil organic biomass & water infiltration, improves soil structure and contributes to the nutrient cycle and soil composition Natural Farming recognizes the natural interdependence of soil, microbiome, plants, animals, climate and human agricultural requirements. Since last decade, concerted efforts are being undertaken in India to create the right perspective among different stakeholders to adopt science based natural farming practices. Major challenges facing natural farming in India includes yield uncertainty and initial lower production, difficulties in pest and disease management compared to chemical farming, labor-intensive practices, and shortages of natural inputs. Farmers face limited access to markets and training, a lack of standardized certification, insufficient government policy support and funding, and general lack of awareness among farmers subsequently Strategies for improving natural farming in India is diversifying crops through intercropping and crop rotation, recycling on-farm organic matter, Policy shifts are also crucial, such as reallocating subsidies towards natural farming inputs and establishing farmer-to-farmer learning networks, supported by scientific research and documentation of traditional practices. India can safely shift 2% of cultivated area each year from conventional farming to organic or natural farming (ONF) without any effect on food supply and has scope to replace around 20 per cent of area from conventional farming to ONF by 2030.

Key words: Natural farming, Niti Ayog, Organic or natural farming, labor-intensive, policy shifts, traditional practices

Introduction:

Natural Farming (NF) is understood as a chemical free farming practice involving livestock integrated natural farming methods and diversified crop systems rooted in the Indian traditional knowledge. Natural Farming is best learnt through practice and experimentation, NF follows local agro-ecological principles rooted in local knowledge, location specific technologies and evolved as per the local agro-ecology. Increased cropping intensity through multiple cropping systems, increased soil organic matter and soil fertility, increased dietary diversity to farmers, reduced cost of production, etc. are some of the benefits of natural farming.

Many agricultural products based on indigenous fermentation technologies are used in organic farming. Cow dung is an integral component of all these preparations and serves as a source of inoculum of beneficial microorganisms. Presence of naturally occurring beneficial microorganisms, predominantly bacteria, yeast, actinomycetes, and certain fungi have been reported in cow dung. Understanding of NF is based on the traditional agriculture systems that are prevalent across the country. Practices such as use of natural inputs, mulching, green cover etc increases the soil organic biomass & water infiltration, improves soil structure and contributes to the nutrient cycle and soil composition. Multi-cropping systems and water management practices involving models such as mulching, trap crop, border crops, rainwater harvesting grid blocks, trenches, ponds, etc. support diverse soil microbiomes thereby suppressing soil-borne diseases, improving soil nutrient cycling, with higher soil water moisture holding capacity and better soil health. Growing a variety of crops creates habitats for a wide range of organisms, including beneficial insects, birds, and other wildlife providing ecosystem services such as pollination, natural pest control, maintenance of natural food cycle (predator-prey relationships which reduces the likelihood of pest outbreaks), suppresses weeds through varied crop canopies and planting schedules, etc.

Crop yield at farmer's field in natural farming is the most debatable issue. Crop yield trend with natural farming during field survey of NF farmers about crop yield during past 3 years suggests that in three states, the yield is more or less stable over the past three years for almost all the crops. Data further report that natural farming practices could not yield as much as conventional farming, however when natural farming practices was augmented with even smaller quantity of FYM, it invariably gave better crop yield than those from conventional/ chemical farming (Kumar et al., 2023). Natural Farming has the potential to significantly reduce production expenses as it uses Jivamrita, Bijamrita, Acchadana (Mulching), and Whapasa which costs very less and are locally available. The continual retention of crop wastes replenishes soil fertility and aids in soil health maintenance. There are several benefits of covering the soil with dust or plant materials (Acchadana/ mulching). One of mulch's main advantages is that it helps to retain soil moisture (Sarangi et al., 2021). It protects the soil from erosion. Besides, it improves soil aeration and conserves soil moisture by checking evaporation water loss. Weed emergence is to some extent checked through mulching. Mulching increased soybean seed yield as well as plant biomass and nodule mass. Soil physical qualities improved as mulching rates increased Further, organic type of mulches such as dried plants additionally produces humus on decomposition, which supplies nutrients to the crop. An ideal microclimate for microbes and local earthworms can be established through using straw mulch.

Chemical-free agriculture, popularly known as organic agriculture, has been gaining importance in India since 2000 (APEDA, 2023). Now in place of organic farming where externally purchased inputs are permitted, natural farming based on avoidance of external input use beyond local and native ecology and indigenous low-cost integrated farming practices is being led by farmers and civil society and has spread to states such as Andhra Pradesh, Karnataka, Himachal Pradesh, Gujarat, Tamil Nadu and Maharashtra and other states in the last few decades. Nearly 2.7% of the total area under farming in India, is farmed organically or through natural methods, which means using natural processes and inputs to improve the soil health, crop yield and quality, a move away from commonly used chemical fertilizers and pesticides.

Since last decade, concerted efforts are being undertaken in India to create the right perspective among different stakeholders to adopt science based natural farming practices. India can safely shift 2% of cultivated area each year from conventional farming to organic or natural farming (ONF) without any effect on food supply and has scope to replace around 20 per cent of area from conventional farming to ONF by 2030. Technologies based on agro-ecological principles especially on ONF are enabling fast changes in food production systems across the world with attractive opportunities to small farms in view of the premium price tag, and quality organic input supply. However, the low yield, nitrogen deficiency, the speed and scale of ecosystem services effect on food security and profitability are the important factors which will decide the mass scale adoption of natural farming.

The National Institution for Transforming India (NITI) Aayog has also emphasized on ‘natural farming’. However, community organization and farmers use ‘organic’ and ‘natural’ farming terms interchangeably. It is roughly estimated that around 2.5 million farmers in India are practicing regenerative agriculture. In the next 5 years, it is expected to reach 20 lakh hectares in any form of organic farming, including natural farming, of which 12 lakh hectares are under Bharatiya Prakritik Krishi Padhati. States such as Andhra Pradesh, Himachal Pradesh, Gujarat, Haryana, Karnataka and Kerala are promoting natural farming. Andhra Pradesh is the front runner among all states in implementing natural farming programme at a mass scale. According to the Andhra Pradesh government, as of March 2020, 0.62 million farmers (10.5 per cent of all farmers) were enrolled in the programme. Of the enrolled farmers, 0.44 million farmers (7.5 per cent), were actually practising natural farming on an area of 0.45 million acres, which works out to 2.9 per cent of the net sown area spread across 3,011 numbers of gram panchayats. Karnataka recently initiated implementation of ZBNF on a pilot basis in 2,000 hectares in each of the 10 agro-climatic zones of the state. Only a few farmers have been doing it at individual scale in other states. Himachal Pradesh has initiated the Prakritik Kheti Khushal Kisan since May 2018 to promote natural farming in the state. Kerala, Gujarat, Haryana and Rajasthan have conducted multiple mass level awareness programmes, trainings and workshops for hundreds and thousands of farmers to promote natural farming. To motivate farmers to adopt chemical free farming and enhance the reach of natural farming, the Government has formulated National Mission on Natural Farming (NMNF).

A planned transition towards a mass movement (Jan Bhagidari) for natural farming needs to be scientifically backed up and requires dedicated long-term investment by the scientific research and extension systems. thus, moving towards sustainability, climate resilience and safe food with scientifically backed Natural Farming approaches.

It is also important for us to consider and collectively assess holistic evidence on the economic and environmental benefits that can be consolidated with natural farming, instead of just focusing purely on crop yields. There is a need to develop a roadmap that sets the long-term agenda for adoption of agro-ecological approaches across different parts of the country. Similarly, there is a need to specifically focus on supporting farmers during the transition to organic and natural farming through technical and financial support. Existing farmer subsidies and related policies should be reoriented to the promotion of on-farm and community based organic concoctions, manures and bio-fertilizers instead of synthetic chemical fertilizers.

Principles of Natural Farming

Natural Farming recognizes the natural interdependence of soil, microbiome, plants, animals, climate and human agricultural requirements. Natural farming is location specific and follows the agro-ecological principles and is rooted in the local knowledge. Practice of natural farming, hence, varies from region to region, however in line with the design of the natural ecosystem, all the natural farming practices follow principles that are given below:

1.Increased organic matter in the soil
2. Minimum soil disturbance
3. Diversified cropping systems
4. Round-the-Year Soil Cover (365DaysSoilCover)
5. Integration of livestock
6. Pest management through Natural farming methods

7. No synthetic chemical inputs
8. Use of On-farm made natural farming bio-inputs
9. Use of locally adapted seeds.

Reason for adopting natural farming

own deep-seated interest and passion for sustainable agriculture. individual decision was driven not only by personal curiosity but by a strong commitment to ensuring a healthier and more sustainable future for the next generation. farmer recognized the long-term benefits of natural farming in preserving soil health, reducing environmental impact, and providing chemical free produce. This sense of responsibility towards future generations played a crucial role in his choice, as he aimed to create a farming system that would sustain both the land and the community for years to come.

Challenges in natural farming

One of the major challenges in natural farming is the difficulty in controlling weeds, as the practice avoids the use of chemical herbicides. Farmers must rely on labor-intensive manual weeding or natural methods, which can be time-consuming and less efficient, leading to increased labor costs and effort. This challenge is compounded by the issue of controlling weeds, which remains a significant problem in natural farming due to the avoidance of chemical herbicides. Managing weeds manually requires substantial time and labor, making it more labor intensive than conventional farming. Additionally, pests and diseases pose significant challenges in natural farming since synthetic pesticides are not used. Farmers must adopt alternative, organic pest management techniques, which may not always be as effective or readily available, leading to potential crop losses. Another critical challenge is the delay in receiving certification for natural farming. Certification is essential for farmers to market their produce as organic or natural and to access higher-value markets. Without timely certification, farmers may face difficulties in commanding premium prices for their products, which can limit their income potential and discourage others from adopting natural farming practices. Another major difficulty in natural farming is finding reliable markets for their natural or organic produce. Despite the growing demand for chemical-free products, many farmers still struggle to establish consistent market connections, leading to uncertainty in selling their produce at fair prices.

Challenges in natural farming in India include yield uncertainty and initial lower production, difficulties in pest and disease management compared to chemical farming, labor-intensive practices, and shortages of natural inputs. Farmers face limited access to markets and training, a lack of standardized certification, insufficient government policy support and funding, and general lack of awareness among farmers. Resistance from the chemical industry and the need for more extensive scientific validation also pose barriers to widespread adoption.

Production & Input Challenges

Yield Uncertainty & Productivity Risks:

Natural farming often leads to initial yield declines, creating income risks for farmers.

Input Availability & Cost:

There's a shortage of readily available natural inputs like cow dung and urine, and higher costs for some inputs compared to conventional farming methods.

Pest & Disease Management:

Natural farming is more vulnerable to high disease and insect attacks compared to chemical farming, requiring effective, but sometimes more complex, natural solutions.

Knowledge & Labor Constraints

Knowledge & Skill Gaps:

Farmers lack adequate training and extension services to learn and implement complex natural farming techniques and prepare bio-inputs.

Labor Intensity:

Natural farming practices are highly labor-intensive, requiring significant manual effort for tasks like weeding and preparing inputs, contributing to labor shortages and increased costs.

Market & Policy Issues

Marketing & Certification:

There's a significant lack of organized value chains, farmer-friendly certification processes, and adequate market linkage to ensure farmers can sell their produce at fair prices.

Policy & Funding Gaps:

Natural farming receives significantly less government funding and support compared to the well-established chemical farming sector, and policies are often not tailored to support natural farming.

Lack of Scientific Validation:

There is a need for more large-scale, long-term scientific studies to validate the sustainability and long-term productivity of natural farming across different agro-climatic zones.

External & Systemic Barriers

Industry Resistance:

The established chemical farming industry, a capital-intensive sector, naturally discourages efforts towards natural farming.

Climate Change:

Natural farming practices are more susceptible to the impacts of climate change-induced weather extremes, further increasing risks of crop failure.

Strategies for improving natural farming in India

Includes diversifying crops through intercropping and crop rotation, recycling on-farm organic matter via composting and mulching and using locally prepared bio-inputs like Beejamrut and Jeevamrit. Policy shifts are also crucial, such as reallocating subsidies towards natural farming inputs and establishing farmer-to-farmer learning networks, supported by scientific research and documentation of traditional practices.

Farm-Level Strategies

Crop Diversification:

Implement mixed cropping, intercropping, and crop rotation to prevent soil exhaustion, break pest cycles, and enhance soil nutrients.

Soil Enrichment:

Use locally prepared bio-inputs such as Jeevamrit (fermented microbial culture) and Beejamrut (seed treatment) to improve soil microbiology and health.

Biomass Recycling:

Incorporate on-farm generated biomass, such as crop residues, for mulching to retain soil moisture and enhance fertility.

Minimal Tillage:

Reduce soil disturbance to preserve beneficial microbial and fungal networks in the soil.

Integrated Livestock:

Integrate local breeds of cows into the farming system to provide inputs like dung and urine for bio-fertilizers and bio-pesticides.

Water Management:

Employ techniques like contour farming and water harvesting to improve water retention and usage.

Policy & Institutional Strategies

Subsidies Reform:

Shift agricultural subsidies from chemical inputs to incentives for producing bio-inputs and soil health.

Research & Validation:

Invest in multi-location trials and collaborate with farmers and institutions like KVKs to document and validate natural farming practices.

Knowledge Dissemination:

Create a decentralized learning ecosystem that blends traditional farmer knowledge with scientific approaches through farmer-to-farmer exchanges and capacity-building programs.

Documentation:

Document and disseminate successful natural farming practices nationwide to encourage emulation.

Broader Approaches

Agroecology Focus:

Promote agroecology-based universities to specialize in natural farming research and provide scientific validation.

Public-Private Partnerships:

Form partnerships with civil society and the private sector to help disseminate information and support the scaling of sustainable farming methods.

Monitoring Framework:

Implement a new monitoring and evaluation framework to ensure the effective implementation of natural farming policies.

Opportunities of farmer towards natural farming

The farmer highlighted that natural farming (NF) significantly contributes to improving soil health and enhancing biodiversity. By avoiding chemical inputs and synthetic fertilizers, the natural processes of the soil are restored, allowing it to regain its fertility and structure. This leads to healthier, more nutrient-rich soil that is capable of supporting diverse plant life and sustaining long-term agricultural productivity. In addition to improving soil health, natural farming also promotes biodiversity by encouraging the presence of beneficial insects. Earthworms, for example, play a crucial role in aerating the soil, allowing air and water to penetrate deeper, thus improving soil texture and fertility. Similarly, ants help in breaking down organic matter, creating natural pathways for nutrients to reach plant roots. These natural allies not only support plant growth but also maintain the ecosystem balance, reducing the need for chemical pest control.

REFERENCE

- Kumar R, Kumar S, Yashavanth BS, Meena PC, Indoria AK, Kundu S, Manjunath M. Adoption of natural farming and its effect on crop yield and farmers' livelihood in India. ICAR-National Academy of Agricultural Research Management, Hyderabad, India. 2020;130.
- Kumar R, Kumar S, Yashavanth BS, Meena PC, Indoria AK, Kundu S, Manjunath M. Adoption of natural farming and its effect on crop yield and farmers' livelihood in India. ICAR-National Academy of Agricultural Research Management, Hyderabad, India. 2020;130.
- Akhila A, Entoori K. Role of earthworms in soil fertility and its impact on agriculture: A review. Int. J. Fauna Biol. Stud. 2022;9(3): 55-63.

- Kumar R, Kumar S, Yashavanth BS, Venu N, Meena PC, Dhandapani A, Kumar A.Natural farming practices for chemical-free agriculture: implications for crop yield and profitability. Agriculture. 2023;13(3):647
- APEDA. 2023. Available online at: https://apeda.gov.in/apeda website/organic/data.htm. Accessed on 17 October 2023. Aulakh, C.S., Singh, H., Walia, S.S., Phutela, R.P. and Singh, G
- https://agriculture.hp.gov.in/our-scheme/. Available online. Accessed on 17 October 2023.
- https://education.icar.gov.in/Files/CURRICULLA%20FOR% 20NATURAL%20FARMING.pdf. Available online. Accessed on 17 October 2023.
- https://goau.gujarat.gov.in/index.htm. Available online. Accessed on 17 October 2023.
- https://icar.org.in/1st-meeting-national-committee-natural-farmingorganized. Available online. Accessed on 17 October 2023.
- https://naturalfarming.dac.gov.in/AboutUs/MissionAndObjectives. Available online. Accessed on 17 October 2023.
- https://naturalfarming.niti.gov.in/andhra-pradesh/. Available online. Accessed on 17 October 2023.
- https://naturalfarming.niti.gov.in/gujarat/. Available online. Accessed on 17 October 2023.
- Dhivya et al.; Asian J. Soil Sci. Plant Nutri., vol. 10, no. 4, pp. 301-309, 2024; Article no.AJSSPN.124930.

NATURAL FARMING STRATEGIES FOR CLIMATE-RESILIENT AGRICULTURE IN ANDHRA PRADESH

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ABSTRACT

Agriculture in Andhra Pradesh faces unprecedented climate vulnerability, with erratic monsoons affecting 62% of the population dependent on farming. The state experiences recurrent droughts in the semi-arid Rayalaseema region (500-700mm annual rainfall), devastating cyclones along its coastal belt, and severe groundwater depletion with water tables dropping 2-3 meters annually. Conventional agriculture, centered on chemical fertilizers and water-intensive crops, has exacerbated vulnerabilities by degrading soil organic matter to below 0.5%, depleting groundwater resources, and increasing farmer indebtedness.

Natural Farming (NF) has emerged as a transformative climate resilience strategy through the Andhra Pradesh Community-Managed Natural Farming (APCNF) program—the world's largest agroecology initiative engaging over 750,000 farmers across 8 million hectares. This chapter examines how specific NF practices build systemic resilience against adverse weather conditions through soil-centered approaches that restore ecological balance. Beejamrutham (seed inoculation with beneficial microorganisms) enhances germination rates by 15-20% under moisture stress, providing crucial establishment advantages during delayed monsoons. Laboratory analyses reveal diverse microbial consortiums including Azotobacter, Azospirillum, and Bacillus species that fix nitrogen, solubilize phosphorus, and protect against soil-borne pathogens. Jeevamrutham formulations (fermented microbial brews) restore soil biology while reducing fertilizer costs by 70-80%. Recent studies document soil organic carbon increases up to 46%, available phosphorus up to 439%, and micronutrient improvements ranging from 23-98% within three years of application.

Mulching practices address extreme temperature stress by maintaining soil temperatures 8-12°C lower than unmulched fields, while reducing evaporation rates from 8mm to 3-4mm daily during peak summer. Organic matter recycling builds soil water-holding capacity, with each percentage point increase storing approximately 20,000 gallons more water per acre. Pre-monsoon dry sowing (PMDS) extends effective growing seasons by 15-20 days while preventing soil erosion during intense initial rainfall events. Rabi dry sowing leverages residual soil moisture, reducing irrigation dependency by 30-40%.

Field evidence demonstrates remarkable climate resilience outcomes. Following Cyclone Michaung (2023), NF fields showed 40-50% faster recovery compared to conventional systems due to enhanced soil structure and microbial resilience. In drought-prone Anantapur, women's self-help groups achieved 25% yield increases in pearl millet and 30% in groundnut while reducing input costs by 70%. These practices align with UN Sustainable Development Goals and India's Paris Agreement commitments, offering scalable solutions for climate adaptation in semi-arid regions globally.

1. INTRODUCTION

Andhra Pradesh stands at the epicenter of India's climate-agriculture crisis, where traditional farming wisdom meets the urgent realities of climate change. Spanning diverse agro-climatic zones from the fertile Krishna-Godavari delta to the semi-arid Rayalaseema plateau, the state's 53 million inhabitants depend heavily on agriculture for their livelihoods. Yet this agricultural heartland faces mounting challenges: erratic monsoons, prolonged droughts, devastating cyclones, and depleting groundwater resources that threaten food security and rural prosperity (Khadse et al., 2019).

The Green Revolution's legacy in Andhra Pradesh presents a complex paradox. While chemical-intensive agriculture initially boosted yields and modernized farming practices, decades of synthetic fertilizer application have degraded soil biology, increased input costs, and created dangerous dependencies on external supplies. Groundwater exploitation has intensified, with bore wells deepening from 50 feet in the 1970s to 200-300 feet today, while soil organic matter has declined to critically low levels below 0.5% in many regions (Singh et al., 2023).

Within this context of agricultural distress and environmental degradation, Natural Farming (NF) has emerged as a transformative approach that addresses both climate adaptation and rural development challenges. The Andhra Pradesh Community-Managed Natural Farming (APCNF) program represents the world's largest agroecological transition initiative, engaging over 750,000 farmers across 8 million hectares. This scale of adoption reflects not merely policy intervention but genuine farmer recognition that ecological approaches offer practical solutions to contemporary agricultural challenges (APCNF, 2024).

Recent research by the University of Reading documents significantly higher yields in Natural Farming systems compared to conventional agriculture, accompanied by cooler soil temperatures, enhanced moisture retention, and increased beneficial soil organism populations (Future Economy Forum, 2025). These findings suggest that ecological farming methods deliver both environmental benefits and improved economic outcomes for farming communities facing climate uncertainty.

This chapter examines how specific Natural Farming practices build systemic resilience against adverse weather conditions in Andhra Pradesh. Through detailed analysis of soil biology enhancement, moisture conservation strategies, and community-based adaptation approaches, it demonstrates how traditional agricultural wisdom, enhanced by contemporary scientific understanding, offers pathways toward climate-resilient food systems.

2. CLIMATE VULNERABILITY PATTERNS ACROSS ANDHRA PRADESH

Andhra Pradesh's geography creates distinct vulnerability patterns that demand differentiated adaptation strategies. The state's three primary regions—Coastal Andhra, Rayalaseema, and the Telangana plateau (before bifurcation)—experience unique combinations of climate risks that have intensified over recent decades. Understanding these regional variations provides essential context for evaluating Natural Farming's effectiveness across diverse environmental conditions.

The Rayalaseema region epitomizes semi-arid agricultural vulnerability. Comprising Anantapur, Chittoor, Kadapa, and Kurnool districts, this area receives highly variable rainfall averaging 500-700mm annually—significantly below the national average of 1,170mm. Farmer surveys across the region reveal increasing unpredictability in monsoon timing, intensity, and distribution, making traditional crop calendars unreliable guides for agricultural planning (ScienceDirect, 2025). The region's red lateritic soils, naturally low in organic matter and prone to hardpan formation, struggle to retain whatever precipitation they receive.

Coastal Andhra presents different but equally challenging conditions. The Krishna and Godavari deltas, blessed with alluvial soils and abundant water resources during normal years, face increasing threats from extreme weather events. Cyclone intensity and frequency have increased markedly, with recent storms like Cyclone Michaung (2023) demonstrating nature's destructive potential even in traditionally resilient agricultural systems. The APCNF program documented how Natural Farming crops demonstrated superior resilience during this cyclone, maintaining soil structure and recovering more rapidly than conventional fields (APCNF Global, 2024).

Groundwater depletion affects all regions but manifests differently across the state's geology. In hard rock areas of Rayalaseema, aquifers are shallow and quickly exhausted, forcing farmers to abandon agriculture or shift to less water-intensive crops. In alluvial areas, deeper drilling provides temporary solutions but accelerates long-term depletion while increasing pumping costs beyond many farmers' reach. The proliferation of bore wells from 0.4 million in 1970 to over 2.8

million today reflects both technological advancement and hydrological desperation.

These climate vulnerabilities intersect with socio-economic factors to create compound stress for farming communities. Small and marginal farmers, constituting over 85% of the state's agricultural population, lack resources for climate-resilient infrastructure investments. Their dependence on purchased inputs makes them vulnerable to price volatility, while degraded soils require ever-increasing fertilizer applications to maintain productivity. This vicious cycle of input dependence and environmental degradation creates conditions where climate adaptation becomes not just beneficial but essential for agricultural survival.

3. NATURAL FARMING PHILOSOPHY: REBUILDING AGRICULTURAL ECOSYSTEMS

Natural Farming in Andhra Pradesh represents more than alternative agricultural techniques; it embodies a fundamental philosophical shift toward understanding farms as complex ecological systems rather than industrial production units. This approach, influenced by Masanobu Fukuoka's "do-nothing" farming philosophy and adapted to Indian conditions by agricultural scientist Subhash Palekar, challenges the reductionist paradigm of modern agriculture by embracing biological complexity and ecological interconnectedness (DAC, 2025).

The APCNF model operates on nine universal principles that guide all farming decisions: enhancing soil biology through microbial diversity, reducing external input dependence through natural fertility building, managing microclimates through strategic plant coverage, integrating livestock for nutrient cycling, promoting crop diversification for system stability, encouraging beneficial insect populations for natural pest control, water conservation through soil health improvement, carbon sequestration through organic matter accumulation, and community-led knowledge dissemination (APCNF Global, 2024).

At its core, Natural Farming recognizes soil as a living ecosystem teeming with billions of microorganisms that form the foundation of agricultural productivity. Conventional agriculture's reliance on synthetic inputs disrupts these microbial networks, creating dependencies on external fertilizers and pesticides to perform functions that healthy ecosystems provide naturally. Natural Farming seeks to restore these biological relationships through practices that feed and nurture soil microbial communities while reducing chemical disturbances.

The philosophy emphasizes building resilience rather than maximizing short-term yields—a crucial distinction in climate-vulnerable regions where system stability often proves more valuable than peak productivity. Research indicates that Natural Farming systems prioritize soil health restoration, biodiversity conservation, and water use efficiency over immediate output maximization (Natural Farming DAC, 2025). This long-term perspective aligns with farmers' needs for sustainable livelihoods that can withstand environmental and economic shocks.

The community dimension of Natural Farming philosophy recognizes that agricultural transformation requires social as well as technical change. The approach emphasizes farmer-to-farmer knowledge transfer, collective input preparation, and cooperative marketing arrangements that build social capital while reducing individual risks. This community-centric model contrasts sharply with conventional agriculture's individualistic approach, where farmers compete for markets while bearing adaptation costs alone.

The Indo-German Global Academy for Agroecology Research and Learning (IGGAARL), established in 2023, represents institutional commitment to bridging traditional knowledge with scientific understanding through comprehensive farmer education programs. The academy's 4-year Bachelor's degree in Natural Farming demonstrates how formal educational systems can validate and systematize ecological agricultural knowledge while preparing new generations of farmer-scientists (APCNF Global, 2024).

4. KEY PRACTICES IN NATURAL FARMING

NF in Andhra Pradesh is operationalized through a set of **farm-based practices** that restore soil vitality, reduce costs, and enhance resilience. These practices are interdependent and together create a self-reinforcing ecological system.

4.1 Beejamrutham: Biological Seed Protection Systems

Beejamrutham is a cornerstone of Natural Farming, functioning as a microbial seed treatment that enhances germination, seedling vigor, and stress tolerance under challenging conditions, such as irregular monsoons (ARCC Journals, 2025). It is prepared by fermenting cow dung, cow urine, jaggery, pulse flour, and lime in water for 48 hours, fostering the growth of beneficial microbes including *Azotobacter* for nitrogen fixation, *Azospirillum* for root colonization and growth promotion, and *Bacillus* for pathogen suppression and phosphorus solubilization (ResearchGate, 2021).

Laboratory studies show that the microbial consortium mobilizes nutrients in the immediate seed environment, protects seeds from soil-borne pathogens via competitive exclusion and antibiotic production, and produces growth hormones that stimulate root development. These mechanisms are particularly valuable under moisture stress conditions typical in drought-prone regions of Andhra Pradesh. Field observations in Anantapur report a 15–20% improvement in germination for seeds treated with Beejamrutham compared to untreated controls, even during low rainfall periods (ARCC Journals, 2025).

Effectiveness of Beejamrutham declines over time, requiring immediate use after preparation. Community-based preparation systems help coordinate timely use, reduce labor, and share material costs among farmers (Orgprints, 2014). Economically, improved germination reduces replanting, lowers seed expenditure, and provides early growth advantages against weeds, which can be critical for smallholders operating on tight margins.

Farmers also adapt Beejamrutham to local conditions, such as incorporating salt-tolerant microbes in coastal areas or adding antimicrobial local materials in disease-prone zones, reflecting the dynamic and participatory nature of Natural Farming (ResearchGate, 2021).

4.2 Jeevamrutham: Soil Biology Restoration Through Fermented Inputs

Jeevamrutham, meaning "life elixir," is a core Natural Farming input designed to restore soil biological activity in chemically degraded systems while providing plant nutrition through biological processes (IOSR Journals, 2020). It is prepared by fermenting cow dung, cow urine, jaggery, pulse flour, and farm boundary soil in water for 7–10 days under anaerobic conditions, promoting the multiplication of beneficial bacteria, fungi, and other microorganisms that produce enzymes, growth hormones, and bioactive compounds supporting soil health and crop growth.

There are two main forms: Drava (liquid) Jeevamrutham for immediate nutrient and microbial application to soil and roots, and **Ghana (solid) Jeevamrutham** mixed with organic matter for long-term soil building. Drava provides quick nutrient availability, while Ghana releases nutrients slowly, enhancing soil organic matter over multiple seasons.

Research in Zero Budget Natural Farming systems reports significant soil fertility improvements: soil organic carbon up to 46%, available phosphorus up to 439%, potassium up to 142%, and micronutrient gains including zinc 98%, iron 23%, copper 62%, and manganese 55% within three years (MDPI Agriculture, 2023). Field experiments show yield benefits comparable or superior to conventional fertilizers, e.g., rice yields of 2.775 tons/acre in Masura and 2.625 tons/acre in Hamsa varieties (ResearchGate, 2018).

Jeevamrutham's microbiology supports multiple soil functions: nitrogen-fixing bacteria convert atmospheric N, phosphorus-solubilizing bacteria release bound P, and plant growth-promoting rhizobacteria enhance roots while suppressing soil-borne diseases (ResearchGate, 2014).

Economically, a 200-liter batch covers one acre at 50–80 rupees versus 800–1200 rupees for synthetic fertilizers, enabling smallholders to maintain fertility without debt. Community-based preparation strengthens social networks, reduces labor, and facilitates knowledge sharing through collective material and labor contributions.

4.3 Mulching: Microclimate Management for Climate Resilience

Mulching transforms bare soils into protected, productive landscapes, providing critical microclimate regulation under Andhra Pradesh's extreme conditions. By covering soil with organic residues—such as crop straw, groundnut shells, dried grasses, or field weeds—mulching reduces evaporation from 8mm to 3–4mm daily, moderates soil temperatures by 8–12°C, suppresses weeds, and supports root and microbial activity (CEEW, 2023).

As mulch decomposes, it gradually adds organic matter, enhancing soil fertility, structure, and water retention. Material choice reflects local availability: rice straw in delta regions, groundnut shells in dry districts, and field grasses or residues elsewhere. Proper timing is essential—too early can hinder emergence or harbor pests, while too late may leave crops stressed.

Seasonal strategies optimize benefits: monsoon mulching prevents erosion and manages excess moisture, while post-monsoon mulching conserves water and regulates temperature during dry growth periods. Farmers report improved soil texture, color, and long-term resilience within one to two seasons, making mulching a cornerstone of Natural Farming adaptation to extreme weather

4.4 Organic Matter Cycling: Enhancing Soil Health and Water Retention

Organic matter recycling transforms agricultural residues into valuable soil amendments, addressing the critical challenge of rebuilding degraded soils in Andhra Pradesh. Soil organic matter improves structure, binds mineral particles into stable aggregates, slowly releases nutrients, and enhances water-holding capacity—each 1% increase storing roughly 20,000 gallons of water per acre (IJARESM, 2025).

Farmers utilize diverse local materials: rice hulls and straw in delta regions, cotton stalks and leaves in cotton-growing areas, and groundnut shells in dry regions. Simplified composting, often inoculated with **Jeevamrutham**, accelerates decomposition while reducing labor. **Vermicomposting** adds premium nutrients and beneficial microbes, and livestock integration converts residues into manure while producing milk, meat, and fiber.

Green manuring with nitrogen-fixing crops such as sunhemp, dhaincha, and sesbania further enriches soil fertility and organic matter content. These crops can be intercropped or grown during fallow periods, enhancing nutrient cycling, soil structure, and long-term resilience, making farms more productive and climate adaptive.

4.5 Dry Sowing for Climate-Resilient Crop Establishment

Dry sowing, encompassing **Pre-Monsoon Dry Sowing (PMDS)** and **Rabi Dry Sowing**, is a cornerstone of Natural Farming for managing climate variability and optimizing water use efficiency. **PMDS** involves sowing seeds in advance of monsoon onset, allowing immediate germination with the first adequate rainfall. This early establishment mitigates risks from delayed or irregular monsoons and extends the effective growing period by 15–20 days, which can significantly enhance crop productivity and economic returns. Minimal soil disturbance techniques, such as shallow furrows or dibbling, preserve soil aggregation, organic matter, and microbial activity, aligning with the principle of working in harmony with soil ecosystems. Drought-tolerant traditional varieties, often overlooked in conventional agriculture, are particularly suited for PMDS due to their rapid germination and stress resilience. Community coordination of sowing activities further strengthens social resilience, enabling collective labor sharing, synchronized sowing, and knowledge exchange among farmers.

Rabi Dry Sowing extends these principles to post-monsoon crop establishment, leveraging residual moisture from the kharif season to establish rabi crops without immediate irrigation. Enhanced soil organic matter and mulching increase water-holding capacity and maintain soil moisture for longer periods, allowing successful cultivation of shallow- and deep-rooted crops in water-limited regions. Integration with kharif crop management—through residue retention, timely harvest, and immediate field preparation—ensures optimal conditions for rabi establishment. Village-level seed banks and community-managed variety sharing support genetic diversity and the availability of climate-adapted cultivars.

Combined, PMDS and Rabi Dry Sowing enhance **soil moisture retention, reduce irrigation dependency, minimize erosion, and improve crop establishment under climate stress**, while creating significant economic and ecological benefits. Studies from Andhra Pradesh demonstrate that such integrated dry sowing systems can **increase effective water availability by 30–40%**, improve erosion control on sloping lands, and enable farmers to sustain double cropping even in semi-arid regions, building robust climate-resilient farming systems.

5. System Integration: Synergistic Resilience Building

The transformative power of Natural Farming emerges not from individual practices but from their synergistic interactions that create agricultural systems capable of withstanding multiple simultaneous stresses. This whole-system approach addresses the reality that climate challenges rarely occur in isolation—droughts may be followed by floods, heat stress may coincide with pest outbreaks, and economic shocks may compound environmental stresses.

Research on agricultural system redesign through Natural Farming demonstrates how individual practices combine to create emergent properties exceeding the sum of their parts

(Taylor & Francis, 2019). Enhanced soil biology from Beejamrutham and Jeevamrutham applications improves effectiveness of mulching and dry sowing practices. Healthy soils with active microbial communities better retain moisture applied through mulching while providing improved growing conditions for dry-sown crops.

Nutrient cycling synergies develop as organic matter recycling provides substrates for beneficial microorganisms introduced through biological preparations. These microorganisms accelerate organic matter decomposition and nutrient release while improving soil structure and water-holding capacity. This biological activity creates positive feedback loops that gradually reduce dependence on external inputs while maintaining or improving productivity.

Water management integration represents perhaps the most critical synergy for climate adaptation. Enhanced soil organic matter increases water-holding capacity, mulching reduces evaporation losses, biological activity improves soil structure for better infiltration, and strategic cropping patterns optimize water use efficiency. These combined effects can increase effective water availability by 30-40% compared to conventional systems, providing crucial resilience during extended dry periods.

Pest and disease management synergies emerge from biodiversity enhancement and biological balance restoration. Diverse crop rotations break pest cycles, beneficial insect populations control harmful species, and healthy soil microbiomes suppress soil-borne diseases. This biological pest control reduces pesticide requirements while improving ecosystem stability and human health outcomes.

Economic synergies develop as reduced input costs, improved yields, and enhanced risk management create more stable and profitable farming systems. Initial transition periods may involve temporary income reductions, but systematic Natural Farming adoption typically results in improved economic outcomes within 2-3 years as soil health recovery enables productivity gains.

Knowledge system synergies strengthen community resilience through farmer-to-farmer learning networks, collective problem-solving, and shared risk management. These social dimensions of Natural Farming adoption create adaptive capacity that enables communities to respond effectively to novel challenges and changing conditions

6. BUILDING SYSTEMIC RESILIENCE

While each NF practice contributes specific benefits, their real impact emerges from **synergy at the system level**. When combined, these practices transform farming from a fragile, input-dependent system into a **self-sustaining, climate-resilient agroecosystem**.

6.1 Resilience to Droughts

In drought-prone Rayalaseema, NF practices like mulching, PMDS, and organic matter recycling significantly **reduce crop failures**. Fields under NF have been observed to maintain green cover and soil moisture even when neighboring chemically farmed fields show wilted crops. Farmers report that livestock integration and crop diversification further provide **buffer income streams during dry spells** (Reddy et al., 2020).

6.2 Resilience to Floods and Cyclones

In coastal districts like Guntur and Krishna, NF fields have shown **faster recovery after floods and cyclones**. Mulched soils resist erosion, while diversified cropping reduces total losses compared to monocultures. NF's emphasis on soil structure and root depth means that crops can withstand waterlogging better than conventionally farmed fields (APCNF, 2021).

6.3 Socio-Economic Resilience

NF lowers cultivation costs by reducing dependence on fertilizers, pesticides, and purchased seeds. This directly reduces farmer indebtedness—a major driver of agrarian distress in India. At the same time, NF promotes **collective action through women's Self-Help Groups (SHGs)**, strengthening social resilience and empowering rural communities.

6.4 Nutritional and Ecological Resilience

NF crops are often richer in micronutrients and free from chemical residues, offering consumers healthier food choices. Ecologically, NF farms harbor more biodiversity—from pollinators and soil fauna to birds and beneficial insects—thereby creating a **virtuous cycle of ecological stability**.

In short, Natural Farming in Andhra Pradesh has moved beyond individual techniques to foster **whole-system resilience**, positioning the state as a global laboratory for climate-resilient agriculture

7. CASE STUDIES FROM ANDHRA PRADESH

The strength of Natural Farming in Andhra Pradesh is best illustrated through **field-level experiences**. These stories highlight how farmers, communities, and districts have harnessed NF practices to withstand climate shocks, reduce input costs, and regenerate ecosystems.

7.1 Women's Self-Help Groups in Anantapur

Anantapur district, part of the drought-prone Rayalaseema region, has historically struggled with **crop failures and farmer distress**. Through the support of Self-Help Groups (SHGs), thousands of women farmers adopted NF practices such as Beejamrutham, Jeevamrutham, and mulching.

These women reported **significant reductions in cultivation costs**, enabling them to save money for household needs and education. In years of below-normal rainfall, NF fields produced enough groundnut, millets, and pulses to ensure household food security. The **collective action of SHGs** also created strong community resilience, where women exchanged seeds, shared bio-inputs, and jointly marketed surplus produce (Khadse et al., 2018).

7.2 Cyclone Recovery in Coastal Guntur

In 2020, cyclone Nivar devastated parts of coastal Andhra. Farmers in Guntur practicing conventional agriculture reported **complete crop losses**. However, NF farmers with mulched soils and diversified cropping patterns showed **quicker recovery**. Banana plantations treated with Jeevamrutham survived flooding better than chemically farmed plots, while intercropped vegetables recovered rapidly.

This case demonstrates how NF creates **ecosystem buffers** against extreme climatic events. Farmers not only avoided debt from replanting but also maintained market supply of vegetables in the post-cyclone period, earning premium prices.

7.3 Krishna Murthy, Chittoor District

A widely cited success story is that of **Krishna Murthy**, a farmer from Chittoor district. Initially skeptical, he adopted NF practices after experiencing rising input costs and declining soil fertility. By integrating PMDS, mulching, tree components and organic matter recycling, his farm transformed into a **diverse, resilient system**.

He reported a **50% reduction in input costs** and stable yields even in years of erratic rainfall. Beyond economics, Krishna Murthy noted improvements in soil texture, water retention, and crop taste. His farm became a **demonstration site** for many farmers globally showing how NF can revitalize both livelihoods and landscapes. In 2025, As part of Organic kuppam Honourable CM Nara Chandra Babu visited Krishna Murthy's field and appreciated him and announced organic kuppam in vision kuppam.

7.4 District-Level Transformation in Vizianagaram

Vizianagaram district provides an example of **NF at scale**. Here, local governance bodies collaborated with farmer groups to integrate NF into watershed management projects. Through mulching, PMDS, and crop diversification, the district reduced groundwater extraction and improved soil organic carbon levels.

Reports indicate that **migration rates declined** as farmers found year-round livelihoods locally. The initiative highlights the potential of NF as a **district-wide climate adaptation strategy**, moving beyond individual farms to landscape-level transformation (APCNF, 2022).

8. POLICY, GLOBAL RELEVANCE, AND FUTURE PATHWAYS

8.1 Policy Framework in Andhra Pradesh

The scaling of NF in Andhra Pradesh is not merely a grassroots movement but also a **state-**

supported policy initiative. The **Andhra Pradesh Community-managed Natural Farming (APCNF)** program, launched in 2016, aims to transition all six million farmers in the state to NF by 2030.

The program adopts a **community-driven extension model**, where trained farmer practitioners (Krishi Mitras) spread knowledge through peer learning. Women's SHGs are central actors, ensuring social inclusivity and gender equity. Government support includes training, farmer field schools, digital tools, and market linkages for NF produce (Government of AP, 2021).

8.2 Alignment with Global Frameworks

NF resonates with multiple **international sustainability frameworks**:

- **Sustainable Development Goals (SDGs)**: NF directly advances SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action).
- **Paris Agreement**: By enhancing soil carbon sequestration, NF contributes to climate mitigation while strengthening adaptation.
- **FAO Principles of Agroecology**: NF embodies FAO's 10 elements of agroecology—diversity, co-creation of knowledge, recycling, synergies, efficiency, resilience, human and social values, culture and food traditions, circular economy, and responsible governance (FAO, 2019).

8.3 Natural Farming and Carbon Markets

A future opportunity lies in **linking NF with carbon markets**. By increasing soil organic carbon, reducing fertilizer-related nitrous oxide emissions, and enhancing agroforestry integration, NF can generate **verifiable carbon credits**. This creates new income streams for farmers while positioning Andhra Pradesh as a leader in nature-based climate solutions (Lal, 2020).

8.4 Role of Digital Tools and Innovation

Digital platforms are increasingly used to **monitor soil health, track yields, and connect farmers with markets**. Apps developed under APCNF provide real-time guidance on NF practices, while remote sensing helps verify soil moisture and biomass changes. Integrating artificial intelligence, drones, and blockchain-based traceability could further **scale NF globally** while ensuring transparency for consumers and policymakers.

8.5 Lessons for Global Agroecology

The Andhra Pradesh experience provides a **replicable model** for other regions facing climate stress. Key lessons include:

- Building movements around **community institutions** rather than top-down extension.

- Ensuring **low-cost, accessible practices** that do not burden farmers with debt.
- Demonstrating **policy commitment** at scale, enabling institutional trust and long-term continuity.

Thus, NF in Andhra Pradesh is not only a **state-level innovation** but also a **global beacon** for agroecological transitions.

9. CONCLUSION

The journey of Andhra Pradesh from a climate-vulnerable state to a **pioneer in Natural Farming** offers powerful insights into the future of agriculture. In a context marked by droughts, cyclones, declining soil fertility, and farmer distress, NF has emerged as a **transformative solution** rooted in ecological principles and community empowerment.

By leveraging practices like Beejamrutham, Jeevamrutham, mulching, organic recycling, and dry sowing, NF has enhanced the **adaptive capacity of both ecosystems and communities**. Its emphasis on farmer knowledge, women's empowerment, and cost reduction has further created **social and economic resilience**.

At the systemic level, NF embodies a paradigm shift: from agriculture dependent on external inputs and vulnerable to climate shocks, to farming that regenerates soils, nurtures biodiversity, and sustains livelihoods. The Andhra Pradesh experience demonstrates that **scaling agroecology is not only possible but also essential** for meeting the challenges of food security, climate change, and rural development in the 21st century.

As the world seeks sustainable pathways to feed its population while respecting planetary boundaries, **Natural Farming stands as both a local success and a global imperative**. The case of Andhra Pradesh reminds us that resilience is not built by resisting nature, but by **working in harmony with it**.

REFERENCES

1. Anderson, C. R., Bruil, J., Chappell, M. J., Kiss, C., & Pimbert, M. P. (2019). *From transition to domains of transformation: Getting to sustainable and just food systems through agroecology.* Sustainability, 11(19), 5272.
2. APCNF. (2021). *Community Managed Natural Farming in Andhra Pradesh: Annual Report.* Government of Andhra Pradesh.
3. APCNF. (2022). *Scaling Agroecology: Lessons from Andhra Pradesh.* Rythu Sadhikara Samstha.

4. FAO. (2019). *The 10 Elements of Agroecology: Guiding the Transition to Sustainable Food and Agricultural Systems.* Rome: FAO.
5. Government of Andhra Pradesh. (2021). *Natural Farming Policy Note.* Department of Agriculture, AP.
6. Government of Andhra Pradesh. (2022). *Statistical Abstract of Andhra Pradesh.* Directorate of Economics & Statistics.
7. Khadse, A., Rosset, P. M., Morales, H., & Ferguson, B. G. (2018). *Taking agroecology to scale: The Zero Budget Natural Farming peasant movement in Karnataka, India.* Journal of Peasant Studies, 45(1), 192–219.
8. Lal, R. (2020). *Soil organic matter and water retention: Implications for climate change.* Agronomy Journal, 112(5), 3265–3277.
9. Reddy, D. N., Prasad, S. C., & Kumar, P. (2020). *Agrarian distress and natural farming in Andhra Pradesh.* Economic & Political Weekly, 55(42), 23–27.
10. Singh, R., Kumar, S., & Kaur, M. (2021). *Mulching as a climate-smart practice for dryland agriculture.* Indian Journal of Agronomy, 66(2), 145–152.
11. Subhash Palekar. (2015). *The Philosophy of Spiritual Farming.* Zero Budget Natural Farming Publications.

REVIVING THE ROOTS: THE ROLE OF ORGANIC AND NATURAL FARMING IN ACHIEVING SUSTAINABLE AGRICULTURE IN INDIA

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Abstract

Organic and natural farming have emerged as transformative pathways toward sustainable agriculture in the face of growing ecological imbalances, soil degradation, and overdependence on chemical inputs. These alternative practices emphasize the integration of traditional wisdom with eco-friendly innovations, aiming to restore soil health, promote biodiversity, and enhance long-term farm productivity without harming the environment. India, being a country rooted in ancient agricultural practices like Rishi Krishi and Vedic farming, has a rich heritage to lead this transition. This chapter explores the principles, practices, and potential of organic and natural farming in the Indian context, including successful models like the Zero Budget Natural Farming (ZBNF) in Andhra Pradesh and Sikkim's organic revolution. It further analyzes government policies, market challenges, consumer perceptions, and the economic viability for smallholder farmers. The chapter concludes with strategic recommendations to integrate organic/natural farming with modern-day practices and calls for collaborative efforts from institutions, policy-makers, and communities to ensure a sustainable food future.

Keywords-Organic Farming, Natural Farming, Sustainable Agriculture, Zero Budget Farming, Soil Health, Agroecology, India

Introduction

Agriculture stands at a crossroads. While the Green Revolution brought food security, it also sowed the seeds of unsustainability — soil fatigue, water depletion, and chemical dependence. In this backdrop, organic and natural farming are not just alternatives; they are necessities for ecological survival and long-term food security...

Understanding Organic and Natural Farming

Organic farming involves cultivation without synthetic fertilizers, pesticides, genetically modified organisms...

Case Studies from India

Sikkim became the world's first fully organic state in 2016... Andhra Pradesh's Zero Budget Natural Farming (ZBNF)...

Benefits of Organic & Natural Farming

These practices restore soil fertility, conserve water, reduce emissions, and empower marginalized farmers...

Challenges Faced by Farmers

Yield gaps, certification hurdles, market access issues, and consumer awareness remain key obstacles...

Government Initiatives & Policy Support

PKVY, NPOP, BPKP, and FPO schemes are steps by the government to mainstream these practices...

Recommendations for the Future

Strengthen extension services, improve market linkages, provide incentives, promote consumer education...

Conclusion

Organic and natural farming are not nostalgic ideas; they are scientific and scalable solutions for a better tomorrow... As India aspires for Atma Nirbhar Krishi (self-reliant agriculture), organic and natural farming provide the cultural, ecological, and economic foundation. Let us return to our roots not with nostalgia, but with innovation — and nurture a future where farming heals the Earth, feeds the hungry, and dignifies the farmer.

References

1. Palekar, S. (2016). The Philosophy of Spiritual Farming.
2. Government of India. (2023). Ministry of Agriculture Reports.
3. FAO. (2020). Agroecology Knowledge Hub.
4. Singh, R.K. et al. (2021). Organic Farming in India: Issues and Strategies. Agri Reviews.

Voice from the Field: A Farmer's Journey

Ramesh, a 42-year-old farmer from Warangal district in Telangana, had been practicing conventional farming for over two decades. Each season began with a loan — for fertilizers, pesticides, and hybrid seeds — and ended with anxiety over weather, pests, or market prices. Despite good yields, profits rarely came his way.
In 2020, after attending a natural farming awareness session by an NGO, he decided to experiment on one acre of his land using desi seeds, Jeevamrut, and mulching. The results

surprised him — the soil remained moist even during dry spells, pest attacks were minimal, and his crop was sold at a premium in a local organic haat. By 2023, he had converted his entire 5-acre farm to natural methods. Today, Ramesh is a community trainer, guiding 25 fellow farmers in his village. His success is a testament to the power of grassroots transition.

Comparison: Conventional vs Natural Farming

Farming Method	Input Cost (₹/acre)	Yield (kg/acre)	Net Profit (₹/acre)
Conventional	28,000	1,200	12,000
Natural	10,000	1,000	20,000

Personal Reflection: A Young Agrarian's Perspective

As a graduate in agriculture, my exposure to both scientific practices and traditional wisdom have shaped my understanding of sustainability. While chemical agriculture focuses on short-term productivity, natural farming aligns with the deeper philosophy of coexistence — with the soil, with biodiversity, and with rural livelihoods. During field visits as part of my coursework, I interacted with several farmers who shifted to organic/natural farming. Their stories were not just about yields — they spoke of dignity, empowerment, and self-reliance.

I believe that as future agripreneurs and scientists, we must build bridges — between tradition and technology, between rural realities and policy reforms. Natural farming is not just a technique; it is a movement that deserves scientific recognition, institutional support, and societal embrace.

ROLE OF SULFUR IN *PADDY *

Aleti Sowjanya and Raja kumar

KVK Kondempudi

1. Introduction:

Rice (Oryza sativa) is one of the most important staple food crops globally, particularly in Asia, where it forms the primary source of calories for millions of people. Paddy cultivation, especially in regions with high rainfall and lowland soils, is a major agricultural activity supporting food security and livelihoods. As the demand for higher rice yields increases, efficient nutrient management becomes critical to achieve sustainable productivity.

Among the essential nutrients required by rice plants, Sulfur (S) is often overlooked compared to nitrogen (N), phosphorus (P), and potassium (K), but its role is no less significant. Sulfur is a vital secondary macronutrient involved in a variety of physiological and biochemical processes necessary for healthy plant growth and development. It forms a key component of amino acids, vitamins, and coenzymes, and plays a central role in protein synthesis and enzymatic functions.

Historically, sulfur was supplied unintentionally through atmospheric deposition, particularly in industrial regions where sulfur dioxide (SO_2) emissions were high. However, with modern agricultural practices, cleaner air, reduced industrial emissions, and the use of high-analysis fertilizers devoid of sulfur, many soils now face sulfur deficiencies, especially in paddy-growing regions. This is particularly true in sandy and highly weathered soils, where sulfur is prone to leaching.

Sulfur deficiency in rice manifests as poor plant growth, interveinal chlorosis in young leaves, reduced tillering, and lower grain and straw yields. The impact is not just limited to yield losses but extends to reduced grain quality, especially in terms of protein content, which is of particular importance for nutritional value.

Proper sulfur management through balanced fertilization is essential to maintain soil fertility, improve nutrient use efficiency, and enhance crop resilience to abiotic stresses. It also contributes to maintaining soil health by supporting microbial communities involved in nutrient cycling.

In this chapter, we will explore in detail the physiological role of sulfur in paddy crops, symptoms of deficiency, sources of sulfur fertilizers, application methods, effects on yield and soil health, environmental considerations, and best practices for sustainable sulfur management.

2. Importance of Sulfur in Paddy:

Sulfur plays a critical role in the growth, development, and productivity of paddy (rice) crops. Although it is required in smaller amounts than nitrogen, phosphorus, and potassium, its functions are essential and diverse, impacting various physiological, biochemical, and structural processes within the plant.

2.1. Role in Protein Synthesis and Enzyme Function:

Sulfur is a key component of sulfur-containing amino acids, such as cysteine and methionine, which are essential for the synthesis of proteins in rice plants. These amino acids are building blocks for enzymes, hormones, and structural proteins that regulate cellular metabolism and promote overall plant development.

- **Cysteine and Methionine:** These amino acids are involved in protein folding and stability and are important for the synthesis of coenzymes, vitamins, and secondary metabolites.
- **Enzyme Activity:** Sulfur is critical for the formation of enzyme active sites, especially in enzymes that catalyze redox reactions (such as glutathione reductase), which are important for the plant's defense system against oxidative damage and metabolic regulation.

2.2. Photosynthesis and Chlorophyll Production:

Although sulfur is not a direct component of chlorophyll molecules, it plays a role in the synthesis of chlorophyll by influencing the nitrogen metabolism of the plant.

- **Chlorophyll Content:** Sulfur facilitates the formation of amino acids and proteins needed for chlorophyll biosynthesis. Deficiency leads to interveinal chlorosis, particularly in young leaves, due to impaired chlorophyll production.
- **Energy Production:** By supporting efficient photosynthesis, sulfur ensures optimal production of carbohydrates that are critical for plant growth, grain filling, and yield development.

2.3. Synthesis of Vitamins and Coenzymes:

Sulfur is involved in the production of important vitamins such as biotin and thiamine (Vitamin B1), which are essential cofactors in metabolic processes. These vitamins contribute to energy metabolism and the synthesis of key biomolecules.

2.4. Plant Defense and Stress Resistance:

Sulfur plays a protective role in plants by contributing to the production of glutathione, a tripeptide involved in detoxifying reactive oxygen species (ROS), thus improving the plant's ability to tolerate environmental stresses such as drought, salinity, and pathogen attacks.

- **Glutathione Role:**

Glutathione helps in neutralizing free radicals produced during stress conditions, maintaining cellular redox balance and protecting membranes and proteins from oxidative damage.

2.5. Interaction with Other Nutrients:

- **Nitrogen-Sulfur Relationship:** Sulfur is necessary for the efficient use of nitrogen in protein synthesis. A sulfur deficiency can limit the plant's ability to utilize applied nitrogen, reducing fertilizer use efficiency and leading to poor growth.
- **Phosphorus Availability:** Sulfur can influence phosphorus solubility and uptake, thereby indirectly affecting energy transfer processes within the plant.

2.6. Yield and Grain Quality Improvement:

Proper sulfur nutrition results in:

- **Increased Grain Yield:** Adequate sulfur leads to better tiller formation, panicle development, and grain filling, thereby enhancing yield.
- **Improved Grain Protein Content:** The availability of sulfur directly influences the synthesis of proteins in grains, which is critical for nutritional quality, especially in regions where rice is a primary protein source.
- **Enhanced Straw Quality:** Sulfur also contributes to the production of high-quality straw used as fodder or for other agricultural purposes.

2.7. Soil Health and Microbial Activity:

Sulfur supports a healthy soil ecosystem by promoting the activity of sulfur-oxidizing bacteria (such as Thiobacillus spp.), which help in converting elemental sulfur to plant-available sulfate forms.

- **Nutrient Cycling:** These microbes aid in breaking down organic matter and recycling sulfur within the soil, improving long-term fertility.

3. Symptoms and Diagnosis of Sulfur Deficiency in Paddy:

Sulfur deficiency in paddy crops is becoming increasingly common due to modern agricultural practices that reduce sulfur deposition and the use of high-analysis fertilizers lacking sulfur content. Recognizing deficiency symptoms early is critical for corrective fertilization and avoiding yield loss.

3.1. Visual Symptoms of Sulfur Deficiency:

1. Chlorosis in Young Leaves:

- The most characteristic symptom is uniform yellowing (chlorosis) of young, newly formed leaves.

- Unlike nitrogen deficiency, which affects older leaves first, sulfur deficiency manifests on young leaves, because sulfur is less mobile within the plant.
- Yellowing often starts from the leaf tips and spreads uniformly across the leaf blade.

2. Stunted Plant Growth:

- Plants exhibit poor vegetative growth with reduced height and weak tiller development.
- Overall biomass production declines due to insufficient protein synthesis.

3. Thin, Narrow Leaves:

- Leaves may appear thinner and narrower than normal due to poor cell development.

4. Poor Tillering and Panicle Development:

- In advanced stages, there is a significant reduction in the number of productive tillers.
- Poor development of panicles leads to fewer spikelets per panicle, resulting in poor grain set and yield.

5. Poor Grain Filling:

- Grain development is impaired, resulting in smaller and poorly filled grains with lower protein content.

3.2. Diagnostic Techniques:

1. Visual Inspection:

- Frequent field observation helps in early detection of chlorosis in young leaves.
- Symptoms need to be distinguished carefully from other nutrient deficiencies such as nitrogen, magnesium, or iron, which may show similar yellowing but affect older leaves first.

2. Soil Testing:

- Soil testing is essential to determine sulfur availability.
- Available Sulfate-S (SO_4^{2-}) concentration in the soil should ideally be above 10 mg/kg.
- Low sulfate levels (<10 mg/kg) suggest potential deficiency risk.

3. Plant Tissue Analysis:

- Sulfur concentration in the leaf blades of rice can be tested.
- Critical deficiency level:
- < 0.15% S (in dry tissue) indicates deficiency.
- Optimal range: 0.20% – 0.50%.

4. Chlorophyll Meter (SPAD Meter):

- SPAD readings can provide an indirect estimation of chlorophyll content.

- Lower SPAD readings in young leaves may indicate sulfur deficiency.

3.3. Factors Exacerbating Sulfur Deficiency in Paddy:

- Leaching-Prone Soils: In sandy soils and high rainfall areas, sulfate is highly soluble and easily leached below the root zone.
- Low Organic Matter Soils: Soils poor in organic matter have limited sulfur mineralization, reducing available sulfate.
- Intensive Cropping Systems:Continuous cropping without adequate sulfur replenishment accelerates depletion.
- Reduced Atmospheric Sulfur Deposition:Improved industrial regulations and cleaner energy practices have decreased atmospheric sulfur contributions.

3.4. Differentiation from Other Nutrient Deficiencies:

Deficiency Type	Affected Leaves	Symptoms
Sulfur	Young leaves Uniform yellowing starting at tips,	stunted growth
Nitrogen	Older leaves Uniform yellowing,	general chlorosis
Magnesium	Older leaves,	Interveinal chlorosis
Iron	Young leaves	Interveinal chlorosis with green veins
Zinc	Young leaves	Small, narrow leaves; chlorotic spots

Proper diagnosis is important to avoid incorrect fertilization and ensure that sulfur deficiency is treated appropriately.

3.5. Impact of Delayed Diagnosis:

- If sulfur deficiency is not corrected in time:
- Severe yield loss occurs due to reduced tillering and poor grain filling.
- Protein content in grains drops, affecting nutritional quality.
- Plant susceptibility to abiotic stresses (e.g., drought, pests) increases.

4. Sources of Sulfur Fertilizers for Paddy:

Sulfur fertilizers provide plant-available sulfur in the form of sulfate (SO_4^{2-}) or elemental sulfur that converts to sulfate through microbial activity in the soil. The choice of sulfur fertilizer depends on factors such as soil type, crop needs, sulfur availability, cost, and local recommendations.

4.1. Gypsum (Calcium Sulfate – $CaSO_4 \cdot 2H_2O$):

Properties:

- Contains around 15–17% sulfur and 23% calcium.
- Water-soluble sulfate source, making sulfur readily available to plants.

Advantages:

- Improves soil structure in sodic soils.

- Supplies both calcium and sulfur.
- Economical and widely available.

Disadvantages:

- Low sulfur concentration per unit weight, requiring higher application rates.
- Not suitable for acidic soils, where calcium application may not be desired.

Usage in Paddy:

- Commonly applied during land preparation or as top-dressing at early vegetative stages.

•Rate: 500–1000 kg/ha (depending on soil sulfur status).

4.2. Ammonium Sulfate [$(NH_4)_2SO_4$]:

Properties:

- Contains 21% sulfur and 24% nitrogen.
- Provides both nitrogen and sulfur in one fertilizer, promoting balanced nutrition.

Advantages:

- Readily soluble, providing immediate sulfur supply.
- Useful in sulfur-deficient soils.

Disadvantages:

- May lead to soil acidification if used in excess.
- Cost is relatively higher than gypsum.

Usage in Paddy:

Applied in conjunction with nitrogen fertilizers, especially during early growth stages.

Rate: Based on combined N and S requirements.

4.3. Elemental Sulfur (S^0):

Properties:

- Contains 90–95% sulfur.
- Insoluble and requires microbial oxidation (by Thiobacillus spp.) to convert to sulfate.

Advantages:

- Provides long-term sulfur supply as it slowly oxidizes.
- Economical per unit of sulfur content.

Disadvantages:

- Slow acting; not suitable for correcting acute sulfur deficiencies.
- Requires good soil moisture and microbial activity for effective conversion.

Usage in Paddy:

Best applied during land preparation months before transplanting to allow sufficient time for oxidation.

Rate: 20–40 kg/ha depending on deficiency severity.

4.4. Single Super Phosphate (SSP – $Ca(H_2PO_4)_2 \cdot H_2O + CaSO_4$)

Properties:

- Contains both phosphorus (about 16–20% P_2O_5) and sulfur (around 12–18% sulfate).

Advantages:

- Dual-purpose fertilizer supplying phosphorus and sulfur.
- Well-suited for soils low in both nutrients.

Disadvantages:

- Lower sulfur concentration per unit weight compared to ammonium sulfate.
- Bulkier to transport.

Usage in Paddy:

- Applied during basal fertilization at land preparation.
- Rate: 200–400 kg/ha depending on soil fertility status.

4.5. Potassium Sulfate (K_2SO_4):

Properties:

- Contains around 50% K_2O and 18% sulfur.

Advantages:

- Suitable where both potassium and sulfur are deficient.
- No chloride, making it ideal for chloride-sensitive crops like rice.

4.6. Liquid Sulfur Fertilizers:

Properties:

- Includes solutions like ammonium thiosulfate.

Advantages:

- Fast-acting, especially useful for foliar application or fertigation.
- Useful for quick correction of sulfur deficiency.

Disadvantages:

- Costlier per kg of sulfur.
- Requires specialized application equipment.

Usage in Paddy:

- Foliar sprays during early growth stages for fast symptom correction.
- Fertigation during crop establishment.

4.7. Organic Sources of Sulfur:

- Compost, Farmyard Manure (FYM), and Crop Residues: These materials contain sulfur bound in organic forms that mineralize over time.
- Advantages: Improves soil organic matter and microbial activity while supplying sulfur.
- Disadvantages: Variable sulfur content, slower release, and lower predictability.
- Usage in Paddy: Applied at land preparation; useful for long-term soil fertility management.

Summary Table of Sulfur Fertilizer Sources:

Fertilizer Source	Sulfur Content (%)	Advantages	Disadvantages	Application Timing
Gypsum (15–17%)	Economical	improves soil structure	Bulkier, less concentrated	Basal or early stage
Ammonium Sulfate (21%)	Provides both N and S	fast action	May acidify soil if overused	Along with N fertilizers
Elemental Sulfur (90–95%)	Slow release	long-term supply	Slow acting	requires microbial activity Before planting
Single Superphosphate (SSP) 12–18%	Dual P and S source	Bulkier	lower S per kg	Basal fertilization
Potassium Sulfate (18%)	No chloride	good for chloride-sensitive crops	Expensive	Along with K fertilization
Liquid Sulfur Fertilizers Variable	Fast correction	foliar or fertigation	More costly	Foliar or fertigation
Organic Manures (FYM, compost)	Variable	Improves soil health	slow release	slow acting At land prep

5. Sulfur Fertilizer Application Methods in Paddy:

Correct application of sulfur fertilizers is critical to ensure efficient uptake by the rice crop, minimize losses, and achieve optimal yield. The method of application depends on the type of sulfur fertilizer used, the timing relative to crop growth stages, and soil properties.

5.1. Timing of Sulfur Fertilizer Application:

1. Basal Application (Pre-Planting)

- Sulfur fertilizers like gypsum, elemental sulfur, and single super phosphate (SSP) are often applied before transplanting or seeding during land preparation.
- This helps improve soil sulfur status by ensuring that sulfur is available as the crop establishes.
- Ideal for slow-release sources (e.g., elemental sulfur) that need time for microbial oxidation into sulfate.

2. Top Dressing (Post-Transplanting)

- Applied during early growth stages such as the active tillering phase (20–30 days after transplanting).
- Suitable for soluble sulfur sources like ammonium sulfate and potassium sulfate, which provide immediate sulfate availability.
- Improves sulfur availability when plant demand is high during vegetative growth and early reproductive stages.

3. Foliar Application

- Used for rapid correction of sulfur deficiency symptoms.
- Particularly useful when a visual deficiency is observed in young leaves, and soil application cannot meet immediate needs.
- Example: Foliar spray of ammonium thiosulfate (0.5–1% solution) applied during early tillering.

4. Fertigation

- In systems where water management is controlled (e.g., irrigated paddies with drip or sprinkler systems), liquid sulfur fertilizers can be applied via fertigation.
- Provides uniform distribution and quick availability of sulfur.

5.2. Application Methods by Fertilizer Type:

Fertilizer Type	Application Method	Notes
Gypsum	Broadcast and incorporate during land pre.	Slow acting; improves soil structure
Ammonium Sulfate	Broadcast or band application during top-dressing	Soluble, provides N and S
Elemental Sulfur	Broadcast and incorporate during land preparation	Requires microbial oxidation
Single Super Phosphate	Broadcast and incorporate during basal fertilization	Dual P and S source
Potassium Sulfate	Band placement along with potassium fertilizers	Suitable when K and S are both deficient
Liquid Sulfur Fertilizers	Foliar spray or fertigation	Quick symptom correction in deficiency cases
Organic Manures	Applied at land preparation and incorporated	Improves soil organic matter along with slow sulfur supply

5.3. Important Considerations in Sulfur Application:

1. Soil Moisture:

- Adequate soil moisture is essential for sulfur solubilization and microbial oxidation (for elemental sulfur).
- In flooded paddy systems, sulfate forms are readily available, but in dry periods, oxidation of elemental sulfur slows down.

2. Timing Relative to Crop Growth:

- Early sulfur availability is critical during the tillering and panicle initiation stages, which are key for determining grain yield.
- Late application is less effective, as sulfur needs to be available before or during the rapid vegetative and reproductive growth phases.

3. Avoiding Over-Application:

- Excess sulfur can lead to environmental issues such as leaching into groundwater or soil acidification.
- Following recommended doses based on soil and plant tissue testing is essential.

4. Integration with Other Fertilizers:

- Sulfur fertilizers are often applied together with nitrogen, phosphorus, and potassium fertilizers to ensure balanced nutrition.
- Example: Ammonium sulfate combined with urea as a nitrogen source.

5.4. Practical Example of Sulfur Fertilizer Application Schedule in Paddy:

Growth Stage	Fertilizer Type	Application Method	Purpose
Pre-planting	Gypsum or Elemental Sulfur	Broadcast + Incorporate	Build soil sulfur reserves
15–20 Days After Transplanting	Ammonium Sulfate	Top Dressing	Provide quick S and N supply
25–30 Days After Transplanting	Foliar spray (Ammonium Thiosulfate)	Foliar Spray	Correct early deficiency symptoms
Panicle Initiation Stage	Potassium Sulfate or SSP	Band Placement or Broadcast	Support grain development

5.5. Advantages of Proper Sulfur Application Methods

- Enhanced sulfur use efficiency.
- Minimized losses through leaching or volatilization.

- Timely availability of sulfur during critical growth phases.
- Balanced growth and improved grain quality.

6. Effect of Sulfur Fertilization on Paddy Yield and Quality:

Sulfur fertilization plays a critical role in enhancing both the quantity (yield) and quality (grain characteristics, protein content, straw quality) of paddy crops. Proper sulfur management ensures optimal crop performance throughout the growth cycle, leading to measurable benefits at harvest.

6.1. Effect on Paddy Yield:

1. Increased Tillering and Panicle Development:

- Sulfur promotes active cell division and elongation during vegetative growth.
- Well-supplied sulfur improves tiller production, which directly correlates with the number of panicles formed per plant.
- More panicles per unit area led to increased spikelet number and overall grain yield.

2. Improved Grain Filling:

- Sulfur supports the metabolic processes required for assimilate translocation from leaves to grains.
- Adequate sulfur ensures efficient protein and carbohydrate synthesis, allowing better grain filling.
- Studies show yield increases of 10–15% in sulfur-deficient soils when proper sulfur fertilization is applied.

3. Enhancement in Biomass:

- Sulfur improves photosynthesis efficiency by ensuring the formation of chlorophyll and enzymes involved in carbon fixation.
- Result: Higher biomass accumulation, contributing to greater straw and grain yields.

6.2. Effect on Grain Quality:

1. Protein Content Enhancement

- Sulfur is essential for the synthesis of sulfur-containing amino acids (cysteine, methionine), which are key components of storage proteins in rice grains.
- A sulfur-sufficient crop can produce grains with 8–12% higher protein content compared to deficient crops.
- This improvement is crucial in regions where rice is a primary protein source in the diet

2. Grain Appearance and Nutritional Value

- Proper sulfur nutrition leads to better grain plumpness, uniform grain size, and reduced chalkiness.

- Well-filled grains have higher nutritional value and market acceptability.

6.3. Effect on Straw Quality

- Sulfur enhances structural protein content in straw, improving its utility as fodder.
- Stronger straw reduces lodging (falling of rice plants), which can affect harvesting efficiency and overall yield.
- Sulfur-deficient straw tends to be weak, brittle, and lower in nutritional value for livestock use.

6.4. Effect on Stress Resistance and Disease Control:

- Well-supplied sulfur improves the plant's antioxidant defense system by enhancing glutathione production.
- Healthier plants are more resistant to abiotic stresses (e.g., drought, salinity) and biotic stresses (e.g., pests and diseases).
- Yield stability under sub-optimal conditions is greatly improved with adequate sulfur fertilization.

6.5. Synergistic Effects with Other Nutrients:

- Sulfur improves the efficiency of nitrogen use by enhancing nitrogen assimilation and protein synthesis.
- Well-balanced sulfur application reduces nitrogen losses (e.g., as ammonia volatilization), ensuring more nitrogen contributes to yield and quality.
- The combined effect of nitrogen and sulfur improves overall nutrient balance, leading to optimized plant growth and grain production.

6.6. Research Evidence and Case Studies:

- Case Study (India): A study conducted in Punjab (India) showed that applying 20–30 kg S/ha in addition to NPK fertilization increased rice yield by up to 12% and grain protein content by 10%.
- Global Findings: In regions where soil sulfur is depleted, sulfur fertilization increased rice yields by an average of 1.5 tons per hectare, improving both yield and grain nutritional quality.

7. Long-Term Impact of Sulfur Fertilization in Paddy:

Sulfur fertilization is not only essential for immediate crop needs but also plays a key role in maintaining and improving the long-term fertility and sustainability of paddy soils. Continuous and balanced sulfur management provides multiple long-term benefits for soil health, crop productivity, and environmental sustainability.

7.1. Build-Up of Soil Sulfur Reserves:

- Repeated application of sulfur fertilizers increases the available sulfate (SO_4^{2-}) concentration in the soil over time.
- Soils with adequate sulfur reserves are less prone to developing deficiencies in future cropping seasons.
- Over time, a healthy sulfur reserve supports continuous and balanced nutrient supply, reducing the need for emergency sulfur corrections.

7.2. Improved Soil Fertility:

- Sulfur plays a role in maintaining proper soil pH balance, especially in alkaline soils, where sulfur addition can help in moderating pH levels over time.
- Helps in breaking down organic matter more effectively, enhancing the availability of other nutrients like nitrogen and phosphorus.
- Sulfur also supports the biological activity of sulfur-oxidizing bacteria (Thiobacillus spp.), which contribute to sulfur cycling and overall nutrient availability in the soil.

7.3. Enhanced Nutrient Use Efficiency (NUE):

- Proper long-term sulfur fertilization improves the plant's ability to use nitrogen more efficiently by supporting protein synthesis pathways.
- Long-term balanced fertilization reduces nitrogen losses to the environment (e.g., by ammonia volatilization or nitrate leaching), promoting more sustainable use of applied fertilizers.
- Phosphorus use efficiency is also enhanced because sulfur helps in maintaining soil chemical balance, improving P availability.

7.4. Yield Stability Across Seasons:

- Sulfur contributes to consistent grain yield performance even under variable environmental conditions such as drought, salinity, and soil acidity.
- Studies show that in sulfur-deficient soils, continuous sulfur application prevents yield fluctuations that would otherwise occur due to nutrient imbalances.

Example: In long-term experiments conducted in Asia, rice yields remained stable or improved steadily over several cropping cycles when 20–30 kg S/ha was consistently applied along with NPK fertilizers.

7.5. Improvement in Grain and Straw Quality Over Time:

- Grain protein content and overall grain nutritional quality improve in the long term as the soil sulfur supply becomes more consistent.
- Straw quality also improves, making it better suited for use as livestock feed and reducing losses due to poor straw quality (brittle or weak straw).

7.6. Environmental Sustainability:

- Balanced, long-term sulfur application reduces the risk of environmental pollution compared to excessive or irregular applications.
- Prevents sulfate leaching into water bodies by maintaining moderate, continuous levels in the soil.
- Supports a sustainable farming system by promoting biological sulfur cycling rather than relying solely on synthetic inputs.

7.7. Avoidance of Sulfur Deficiency Re-Emergence:

- In areas prone to heavy rainfall or leaching, regular sulfur application prevents recurrent sulfur deficiency.
- Prevents "hidden hunger," where symptoms are not immediately visible but productivity and quality decline over time.

7.8. Economic Impact of Long-Term Sulfur Management:

- Although there is an upfront cost for sulfur fertilizers, over time, proper sulfur management reduces the need for higher doses of nitrogen and emergency interventions to correct yield losses.
- Long-term yield stability translates into better economic returns for farmers by ensuring predictable grain production and quality.

8. Sulfur's Impact on Soil Microbial Communities in Paddy Systems:

Sulfur plays an important and often overlooked role in supporting the soil microbial ecosystem, which is critical for maintaining soil fertility, nutrient cycling, and the overall health of paddy fields. Microbial activity in paddy soils is particularly important due to the waterlogged, anaerobic conditions common in rice cultivation.

8.1. Sulfur as a Nutrient for Soil Microorganisms

- Sulfur is an essential element for many soil microbes, just as it is for plants.
- Soil microbes require sulfur for the synthesis of sulfur-containing amino acids (cysteine and methionine), enzymes, and coenzymes involved in metabolic activities.
- Adequate sulfur levels in soil support the growth and metabolic activity of beneficial microorganisms, such as bacteria and fungi.

8.2. Role of Sulfur-Oxidizing Bacteria (Thiobacillus spp.):

- Specific groups of bacteria, called sulfur-oxidizing bacteria (SOB), such as Thiobacillus and Acidithiobacillus, oxidize elemental sulfur (S^0) and organic sulfur compounds into plant-available sulfate (SO_4^{2-}).

- Process:Elemental Sulfur (S^0) → (Microbial Oxidation) → Sulfate (SO_4^{2-})
- This biological conversion is crucial because plants absorb sulfur in the sulfate form.
- The presence of sulfur in the soil promotes the activity and population growth of these bacteria, ensuring continuous sulfur availability.

8.3. Impact on Soil Organic Matter Decomposition:

- Sulfur availability supports microbial degradation of soil organic matter (SOM), which leads to the release of sulfur-containing organic compounds.
- Microbial decomposition converts organic sulfur into sulfate, which becomes available for plant uptake.
- Active microbial communities maintain a balance in sulfur cycling, preventing accumulation of non-available organic sulfur forms.

8.4. Effect on Soil Microbial Diversity and Function:

- Balanced sulfur nutrition enhances microbial diversity, especially those involved in nutrient cycling (nitrogen, phosphorus, and sulfur cycles).
- Healthy microbial communities help suppress soil-borne pathogens through competitive exclusion and production of antimicrobial compounds.
- Enhanced microbial activity improves soil structure and aggregation, leading to better aeration and water retention—important in flooded paddy systems.

8.5. Influence on Denitrification and Sulfate Reduction Processes:

- In paddy soils under anaerobic (flooded) conditions, sulfate-reducing bacteria (SRB) such as Desulfovibrio reduce sulfate to hydrogen sulfide (H_2S).
- Proper sulfur management prevents excessive sulfate reduction, which would otherwise lead to toxic H_2S accumulation harmful to plant roots and soil life.
- Balanced sulfur inputs support microbial equilibrium, preventing harmful environmental effects.

8.6. Enhanced Nitrogen Fixation by Microbes:

- Sulfur supports microbial communities involved in nitrogen fixation, particularly in paddy soils where certain diazotrophic bacteria (e.g., Azotobacter, Clostridium) convert atmospheric nitrogen into ammonium.
- Sulfur improves the efficiency of nitrogen fixation processes by contributing to the formation of sulfur-containing enzymes necessary for nitrogenase function.

8.7. Sulfur-Mediated Microbial Antagonism Against Soil Pathogens:

- Sulfur-rich soils promote beneficial microbes that can suppress pathogenic fungi and bacteria through competition or antibiotic production.

- Example: Certain Thiobacillus spp. produce organic acids and antimicrobial compounds that inhibit soil-borne pathogens affecting rice roots and seedlings.

8.8. Long-Term Soil Health Benefits:

- Continuous sulfur management supports a robust microbial ecosystem, which enhances long-term soil fertility and structure.
- Healthy microbial activity contributes to improved nutrient availability, organic matter decomposition, and soil resilience against degradation.
- Maintains a natural sulfur cycle without heavy dependence on synthetic fertilizers.

9. Environmental Considerations in Sulfur Management:

- Proper sulfur management in paddy cultivation is not only important for crop productivity but also for minimizing environmental risks and promoting sustainable agriculture. Mismanagement of sulfur fertilization can have negative consequences on soil health, water quality, and atmospheric pollution.

9.1. Risk of Sulfate Leaching:

- Sulfate (SO_4^{2-}) is highly soluble in water, making it prone to leaching below the root zone, especially in sandy soils or regions with high rainfall.
- In flooded paddy systems, sulfate leaching may be reduced due to waterlogging, but once the field is drained or during dry periods, leaching becomes significant.
- Excess sulfate in groundwater can cause contamination, leading to problems in drinking water and aquatic ecosystems.

►Best Practices to Minimize Leaching:

- Apply sulfur fertilizers based on soil testing and crop requirements.
- Use slow-release sulfur sources (e.g., elemental sulfur) where applicable.
- Split sulfur fertilizer doses to match crop demand rather than applying a large single dose.

9.2. Soil Acidification:

- Sulfur fertilization, especially with ammonium sulfate [$(NH_4)_2SO_4$], may lead to soil acidification over time due to nitrification of ammonium and sulfur oxidation.
- Reaction example:
- $(NH_4)_2SO_4 \rightarrow 2\ NH_4^+ + SO_4^{2-}$ $NH_4^+ \rightarrow NO_3^- + H^+$ → Release of hydrogen ions (H^+) lowers soil pH.
- Acidification reduces the availability of essential nutrients (like phosphorus) and can harm soil microbial communities.

► **Mitigation Strategies:**

- Apply gypsum ($CaSO_4 \cdot 2H_2O$), which does not acidify soil and provides calcium.
- Avoid excessive use of ammonium-based sulfur fertilizers.
- Periodically monitor soil pH and apply lime when necessary to maintain neutral pH.

9.3. Atmospheric Pollution and Sulfur Dioxide Emissions:

- Historically, sulfur pollution came from industrial emissions of sulfur dioxide (SO_2), which deposited sulfur onto agricultural soils.
- With stricter environmental regulations and reduced industrial emissions, this unintentional sulfur input has decreased.
- This reduction is good for air quality but increases the need for intentional sulfur fertilization in agriculture.

► **Consideration:**

- Avoid over-application of sulfur fertilizers, which could lead to sulfur volatilization under high temperatures, emitting sulfur compounds into the atmosphere.
- Foliar sprays and fertigation should be carefully managed to avoid off-target drift or evaporation losses.

9.4. Impact on Water Quality:

- Excess sulfate not taken up by plants can enter surface runoff and drainage systems, contributing to eutrophication of water bodies.
- High sulfate levels in irrigation or drainage water can negatively affect aquatic life and reduce water quality for downstream use.

► **Best Management Practices:**

- Apply sulfur fertilizers based on crop and soil needs to prevent excess buildup.
- Ensure proper field bunding and water management to control runoff.
- Promote the use of cover crops or organic amendments that help retain sulfur in the soil.

9.5. Sulfate Reduction and Hydrogen Sulfide (H_2S) Toxicity:

- In anaerobic, flooded conditions typical of paddy fields, sulfate-reducing bacteria (SRB) convert sulfate into hydrogen sulfide (H_2S) gas.
- Reaction:
- $SO_4^{2-} \rightarrow H_2S$ (via microbial sulfate reduction)
- Excessive sulfate in poorly drained fields can result in toxic H_2S accumulation in the root zone, harming root development and plant health.

► **Prevention Methods:**

- Apply sulfur fertilizers in recommended doses only.
- Ensure proper water management (e.g., controlled drainage) to avoid long-term waterlogging beyond crop needs.
- Maintain good soil aeration, when possible, to prevent excess anaerobic conditions.

9.6. Sustainability of Sulfur Fertilizer Sources:

- Use of organic sulfur sources (e.g., compost, farmyard manure) promotes sustainable agriculture by improving soil organic matter, microbial health, and gradual sulfur release.
- Slow-release sources (elemental sulfur, gypsum) reduce environmental risks compared to high-solubility synthetic fertilizers.

10. Conclusion:

- Sulfur is an essential secondary nutrient for paddy cultivation, playing a key role in protein synthesis, chlorophyll formation, and enzyme function. Deficiency symptoms include yellowing of young leaves, stunted growth, poor tillering, and reduced grain quality.
- Sulfur fertilizers such as gypsum, ammonium sulfate, and elemental sulfur are important for correcting deficiencies and maintaining soil sulfur balance. Proper timing and method of application, based on soil testing and crop needs, ensure effective sulfur use.
- Long-term sulfur management improves soil fertility, enhances nutrient use efficiency, stabilizes yields, and promotes environmental sustainability by preventing issues like leaching and soil acidification.
- Balanced sulfur fertilization is essential for healthy paddy growth, better grain quality, and sustainable farming systems.

References:

- Jones, C. A., & Case, V. W. (1990). Sampling, handling, and analyzing plant tissue samples. In Soil Testing and Plant Analysis (pp. 389–427). Soil Science Society of America.
- Singh, A. K., et al. (2015). Long-term effects of sulfur application on rice yield and soil fertility. International Journal of Agronomy.
- Yara International. (n.d.). Sulfur Deficiency Symptoms and Management in Rice Crops. https://www.yara.us/crop-nutrition/rice/nutrient-deficiencies-rice/sulfur-deficiency-rice/
- Sulphur Institute. (n.d.). Sulfur in Agriculture: Sources, Symptoms, and Yield Response. https://www.sulphurinstitute.org.

MODERN FARMING SOLUTIONS THROUGH AGROTEXTILES

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INTRODUCTION

Agriculture is the largest industry worldwide and one of the earliest occupations of humankind. Despite modernization, it continues to be a vital sector globally. In the present era, agriculture and horticulture have recognized the need to adopt advanced technologies to achieve higher yields, improved quality, and better-tasting agro-products.

Among these technologies, hi-tech farming techniques that incorporate textile structures—known as agrotextiles—play a crucial role. Agrotextiles account for nearly 8% of the total technical textiles market share. Their use contributes significantly to enhancing product quality, increasing yields, reducing crop damage, and minimizing economic losses.

With the growing global population, the pressure on agricultural resources has intensified. Traditional practices relying mainly on pesticides and herbicides are no longer sufficient to ensure food security. Therefore, the adoption of agrotextiles has become essential for sustainable and efficient agricultural production.

DEFINITION

The word "Agro textiles" now is used to classify the woven, nonwoven and knitted fabrics applied for agricultural and horticultural uses covering livestock protection, shading, weed and insect control and extension of the growing season.

NEED FOR AGRO TEXTILES

Agro textiles play a vital role in modern agriculture by addressing multiple challenges faced by farmers and the environment. They prevent soil from drying out, enhance crop yield, and improve product quality while protecting farmers from harmful pesticides. With increasing population pressure and limited resources like land, water, and energy, agro textiles offer sustainable solutions by controlling climate, reducing ecological degradation, and promoting efficient water and energy use. They help prevent soil erosion, support afforestation, and serve diverse applications such as greenhouse covers, fishing nets, and layer separation in fields. Agro textiles also include nets for plants, rootless plants, and grassy areas, as well as sunscreens, windshields, anti-bird nets, and fabrics for managing water during scarcity or abundance. Additionally, they are used as packing materials, in bags for storing mowed grass, for controlling stretch in knitted nets, and as shade for basins, making them indispensable for sustainable farming and resource management.

FIBERS USED FOR AGRO TEXTILES

Agro textiles utilize a combination of synthetic and natural fibers to meet diverse agricultural needs. Commonly used synthetic fibers include nylon, polyester, polyethylene, polyolefin, and polypropylene, with polyolefin being the most extensively employed due to its durability and versatility. Natural fibers such as jute, wool, and coir are also widely used, offering eco-friendly benefits. These natural fibers not only serve functional purposes like soil protection and moisture retention but also degrade over time, acting as natural fertilizers that enrich the soil, thereby promoting sustainable agricultural practices.

TECHNIQUES OF PRODUCING AGROTEXTILE PRODUCTS

Agrotextiles can be manufactured using a variety of fabric production techniques, each offering unique advantages suited to specific applications. The three main methods are weaving, knitting and nonwoven technologies**.**

1. **Woven Fabrics:** Woven agrotextiles are produced on weaving machines, particularly Sulzer projectile weaving machines, which allow the production of light to heavy fabrics in wide widths ranging from 540 cm to 846 cm. These machines can produce nets with mesh sizes varying from 1.8 mm to 40 mm. Other weaving systems, such as air-jet and rapier looms, are less suitable because they lack the required weaving width for agrotextile applications.

2. **Knitted Fabrics:** Knitting, especially warp knitting, is widely used for agrotextiles, more so than weft knitting. Warp-knitted protective nets, produced on raschel machines, are common in agriculture and horticulture. Agro nets can be made in various constructions or lappings, which refer to the specific way yarn systems are interlaced to form the fabric.

3. **Nonwoven Fabrics:** Nonwoven agrotextiles can be produced using several methods, including:

- Needle-punched
- Stitch-bonded
- Thermally bonded
- Hydro-entangled
- Spun-bonded
- Wet-laid

Among these, spun-bonding and needle-punching are the most widely used for agrotextile production. Spun-bonded fabrics offer high and uniform tensile strength in all directions, along with good tear resistance. Needle-punched nonwovens are commonly used for items like plant bags, which provide an eco-friendly alternative to clay pots. Natural fiber nonwoven containers decompose naturally in soil, while synthetic versions allow roots to penetrate through the fabric, supporting healthy plant growth.

PROPERTIES REQUIRED FOR AGROTEXTILES PRODUCTS

Man made fibers are preferred for agricultural products than the natural fibers mainly due to their favorable price performance ratio, ease of transport, space saving storage and long service life, weather resistance, resistance to micro-organisms

1. Withstands solar radiation: Agro textiles are laid over the cultivated areas immediately after sowing or planting. For such application agrotextiles has to withstand solar radiation with varying surrounding temperature.

2. Withstands ultraviolet radiation: Polyethylene is resistant to radiation in the visible range. But UV radiation leads to degradation of molecular chains. Hence when used as an outdoor material polyethylene is treated with the appropriate UV stabilizers. These are special types of carbon black which convert the UV radiation into thermal radiation. Good potential to reduce the impact of UV radiation on plants by light-absorbing or light-reflecting nonwovens (light permeability: 80 to 90% to allow photo synthesis to take place).

3. Bio degradability: Natural fibers like wool, jute, cotton are also used where the bio-degradability of product is essential. Natural polymer gives the advantage of bio-degradation but has low service life when compared to the synthetics.

4. High potential to retain water: This is achieved by means of fiber materials which allow taking in much water and by filling in super-absorbers. While nonwovens meant for the covering of plants show a mass per unit area of 15 to 60 gm/m^2, values between 100 and 500 g/m^2 are reached with materials for use on embankments and slopes.

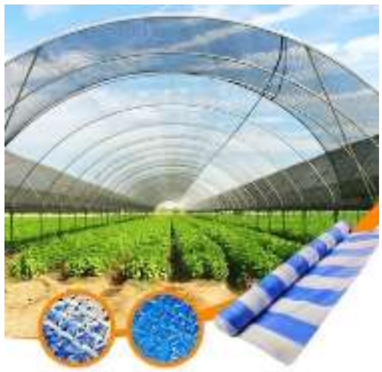
5. Protection property: Protection from wind and the creation of a micro-climate between the ground and the nonwovens, which results in temperature and humidity being balanced out. At the same time, temperature in the root area rise. This is what causes earlier harvests, sufficient stiffness, flexibility, evenness, elasticity, bio-degradability, dimensional stability and resistance to wetness.

APPLICATIONS OF AGRO TEXTILES

Wide varieties of agro textile products are available and the selection of suitable type of products depends on the protection that the crop. Selection of the agro textile is greatly influenced by the geographical location. At some location, agro textiles are used to protect the plantation from excessive sunlight while at some places it is expected to protect plant from cold. Therefore, selection of agro textile is done as per the location and the desired protection from the external agencies. With the use of high quality agro textiles quality and yield of agro products can be enhanced. Some of the applications of agro textiles are as follows:

1. Sunscreens

Quality of nets required will depend on the amount of sunlight required for the crop as compared to that available in a given area. In order to protect fields and greenhouses from the intense solar radiation for healthy plant growth and good harvest.



Sunscreen nets with open mesh construction are used to control sunshine and amount of shade required. These net fabrics allow the air to flow freely. So the excess heat does not built up under the screen.

2. Bird protection nets

Knitted monofilament nets (Open, knitted, nets for crop protection) offer effective passive protection of seeds, crops and fruit against damage caused by birds and a variety of pests. Open-mesh net fabrics are used as a means of protecting fruit plantation. The special open structure repels birds, provides minimal shading and excellent air circulation - allowing plants to flourish, whilst avoiding the risk of dangerous mould developing on the fruit.

3. Plant nets

Plant nets, a key application of agro textiles, are specialized netting systems designed to support and protect plants, particularly those bearing fruits that grow close to the ground, such as strawberries, melons, or certain vegetables. These nets are typically made from durable, lightweight materials like polyethylene, polypropylene, or other synthetic fibers, which provide strength, flexibility, and resistance to environmental factors such as UV radiation and moisture. In some cases, biodegradable natural fibers like jute may be used for eco-friendly applications. The primary purpose of plant nets is to elevate fruits above the soil surface, reducing contact with damp or muddy ground, which minimizes the risk of fruit decay, fungal infections, and pest damage. By doing so, plant nets help maintain fruit quality, increase marketable yield, and reduce post-harvest losses.

4. Ground cover

Ground cover is an extremely versatile landscaping and horticultural fabric for long-term weed control, moisture conservation and separation. It is mainly used in planted areas. It provides weed suppression and ground moisture conservation, whilst allowing roots to breathe and water, air and nutrients to permeate through. This maintains higher soil temperatures and promotes more rapid and even plant growth. It has a high degree of UV stabilizer added to protect it from the harmful effects of exposure to sunlight. It effectively suppresses competitive weed growth, conserves ground moisture, maintains a clean surface, and creates a favorable environment for health plant growth. Ground covers can reduce the costs and minimizes undesirable herbicide use.

5. Windshield

Windshields, also known as wind protection nets or wind-breaks, are a specialized category of agro textiles designed to shield agricultural crops, particularly fruit plantations, orchards, and young plants, from the adverse effects of strong winds. These protective structures are typically made from durable synthetic fibers such as polyethylene, polypropylene, or polyolefin, which offer high tensile strength, UV resistance, and weatherproofing. In some eco-friendly applications, natural fibers like

jute may be incorporated for biodegradability. The primary function of windshields is to act as a barrier that reduces wind velocity to a tolerable level for plants, thereby preventing physical damage, excessive cooling, and related environmental stresses. By moderating wind speed, they help maintain optimal microclimates in fields, which is crucial in windy regions or during seasonal storms, ultimately supporting healthier plant growth and higher yields.

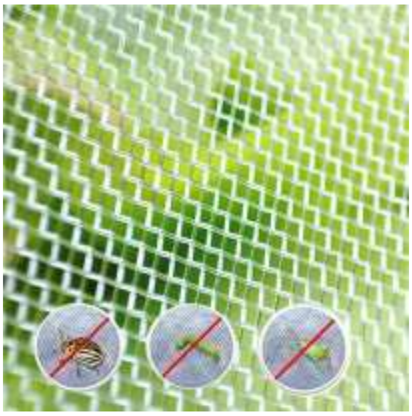
6. Root ball net

Root ball nets are an important agrotextile product designed to protect the root systems of young plants during processes such as digging, transportation, and replanting. For healthy and speedy growth, it is crucial that plant roots remain undamaged and undisturbed when the plant is moved from one location to another. Traditionally, root balls were wrapped in jute or cloth material to hold the soil intact around the roots, but with advancements in agrotextiles, elastic net tubes have emerged as an effective and convenient alternative. These specially designed nets provide strong support to the soil mass around the roots while allowing the plant to breathe and continue its natural growth cycle. One of the most significant advantages of root ball nets is that they do not need to be removed at the time of transplantation. The open mesh structure permits the roots to easily protrude through the net, anchoring the plant firmly in the soil. This not only reduces transplant shock but also ensures continuous root development without interruption. Furthermore, these nets are often made from biodegradable materials, which gradually decompose in the soil after a few months, eliminating the need for manual removal and minimizing environmental impact. Their open and elastic design accommodates growth while maintaining sufficient strength to handle the stress of transport and

handling. Root ball nets are widely used in nurseries, horticultural plantations, landscaping projects, and forestry applications where large numbers of plants are transplanted. By preventing root damage, ensuring soil cohesion, and promoting natural root penetration into the surrounding soil, root ball nets play a vital role in improving the survival rate of transplanted plants and ensuring healthier, more sustainable growth in the long run.

7. Insect meshes

Insect meshes are specialized agrotextile structures designed to protect crops from harmful insect attacks while reducing the dependence on chemical insecticides. These fine woven or knitted meshes, typically made from clear polyethylene monofilament yarns, act as a physical barrier that prevents insects from entering greenhouses, polyhouses, or agricultural tunnels. By excluding pests such as whiteflies, aphids, and thrips, insect meshes help safeguard plants from diseases and damage that these insects often transmit. At the same time, the structure of the mesh is engineered to allow adequate sunlight, air circulation, and moisture exchange, ensuring that plant growth is not compromised. Apart from preventing harmful insects from entering, insect meshes are also used to control pollination by keeping beneficial insects such as bumblebees inside greenhouses, thus aiding in controlled pollination practices. They can be placed over ventilation openings, doors, or even directly on crops for maximum protection. An added advantage of insect meshes is that they enable eco-friendly farming by minimizing or even eliminating the use of chemical pesticides, thereby producing safer and healthier food. Widely used in horticulture, floriculture, and vegetable cultivation, insect meshes contribute to higher yields, improved crop quality, and sustainable agricultural practices.



7. Turf protection net

Turf protection nets are agrotextile structures designed to safeguard grassy areas such as riverbanks, dykes, lawns, and sports fields from damage caused by animal grazing, trampling, or heavy movement. These nets are laid over the surface of the ground to provide a protective layer that prevents the removal of soil in lumps, thereby minimizing soil erosion and promoting land conservation. While offering mechanical strength to the ground, turf protection nets are engineered with an open mesh design that allows grass to grow naturally through the openings without obstruction. As a result, they provide both stability to the soil and support to vegetation development. Their use is especially beneficial in areas prone to erosion, where constant movement of animals or people could otherwise damage the grass cover and

expose the soil beneath. By maintaining healthy turf and preventing erosion, these nets enhance durability, extend land usability, and contribute to effective environmental conservation.

8. Mulch mat

Mulch mats are specialized agrotextile products widely used in horticulture to suppress weed growth and improve crop productivity. By covering the soil surface around seedlings or plants, mulch mats block sunlight, thereby preventing weeds from germinating and competing with crops for nutrients, water, and space. This reduces the dependency on herbicides, making farming more eco-friendly and cost-effective. Commonly, mulch mats are made from **needle-punched nonwoven fabrics** or **black plastic sheets**, with both **biodegradable** and **non-biodegradable** options available depending on the application. Biodegradable mulch mats are particularly preferred for sustainable farming, as they naturally decompose into the soil after use. An effective mulch mat must regulate moisture retention, soil temperature, and light transmission. Ideally, the material should allow minimal or no light to pass through, ensuring that weed development is fully suppressed while maintaining suitable conditions for crop roots. Thus, mulch mats support weed control, conserve resources, and promote healthy crop growth.

9. Monofil nets

Tough, knitted Monofil, nets for windbreak fences and shading/privacy screens. A suitable windbreak, set at a right-angle to the prevailing wind, will protect plants against the harmful effects of blustery weather - which can break young branches, damage flowers and cause leaves to dry or tear. They can also be used to block sand and salinity as well as reduce wind erosion. The nets also protect against frosts and help enhance the micro-climate (Photosynthesis, and ground moisture, is improved by reduced evaporation and transpiration).While special anti-hail net grades have been designed to withstand the impact of heavy hailstorms, when installed in roof-profile above crops and orchards. This not only safeguards the current harvest but also benefits future crops, since the woody part of the plant are protected too.

10. Tape nets

Knitted flat tape nets are available in a wide range of densities for shade, reduced sunlight intensity, fruit support, privacy screening and animal protection. The nets are practical, economical and easy to install; creating ideal growing conditions by avoiding overheating, scorching and moisture loss. The low shade factor nets are used for growing vegetables, while those with medium light-reduction/screening offer ideal conditions for storage areas, cultivating flowering plants/houseplants and acclimatizing plants moved out of greenhouses. In the area of agriculture it is possible to use non-woven blanket fabric that is permeable for water, air and light and during vegetation it creates microclimate optimal for the plant development and growth.

Plants are protected against weather changes (short-term frost), strong wind, hail and pests. Light weight, knitted tape, nets for shade and frost protection. In the alternative agriculture, they often use black mulching fabric that is laid directly on the soil and prevents the growth and spread of weed, which significantly decreases or eliminates the need of herbicides. This fabric is water permeable; it allows the soil to get warm, minimizes non-productive evaporation and prevents creation of soil crust. Pegatex® S - (spun bond) is non-woven fabric manufactured by means of spun bond technology (S) from polypropylene. The basic quality of this type of non-woven fabric is barrier quality, which is used for manufacturing of single-use products. This type of non-woven fabric used in a wide range of applications, from the production of hygienic products (baby nappies, ladies hygiene products, incontinency nappies and towels) to agriculture, building industry or automotive industry.

11. Cherry covers

Growing cherries has proved an uncertain business because of their vulnerability to the weather damage - especially during the blossom, stoning and fruit ripening periods. The new cherry cover system has been specifically designed to tackle these problems; offering protection throughout the season from frost, rain, hail and wind. The fabric is very tough, with a high degree of UV stabilization (to protect against breakdown in sunlight), so will provide many years of use, and the suppleness makes it very easy to handle. The unique property of this system is unrivalled performance. The cover creates a micro-climate (without hindering ventilation) which gives protection against adverse weather conditions - improving both quality and yields.

12. Nets for covering pallets

Nets for covering pallets are practical agrotextile applications designed to ensure the safe handling and transportation of fruits, vegetables, and other perishable goods. During transport, boxes stacked on pallets are prone to shifting, sliding, or even toppling, which can cause significant damage to the produce. To prevent this, large mesh nets are used to cover the stacked boxes securely, holding them firmly in place and stopping them from turning upside down. These nets provide flexibility and strength while allowing airflow around the produce, which is especially important in preventing spoilage during long journeys. They are generally lightweight, reusable, and easy to apply or remove, making them highly efficient for logistics and distribution. By reducing transit-related damage and maintaining the quality of fruits and vegetables, pallet covering nets help minimize economic losses and ensure that goods reach the market in fresh and saleable condition.

13. Packing materials for agricultural products

Packing materials play an essential role in maintaining the quality, freshness, and market value of agricultural products during handling, storage, and transportation. Among the various options, **net-based packaging materials** are widely preferred for fruits, vegetables, and horticultural items due to their unique properties. These include **packing sacks for vegetables, tubular packing nets for fruits**, and even **wrappers for bulky items like Christmas trees**. The net structures are advantageous because they combine **high strength with low weight**, making them easy to handle and cost-effective. Their **air permeability** allows proper ventilation, which prevents the accumulation of heat and moisture, thereby reducing spoilage and extending shelf life. Additionally, the lightweight nature of these nets reduces transportation costs while ensuring that the produce remains stable and secure. The flexibility of net packaging also allows different sizes and shapes of products to be packed efficiently. Importantly, the nets are durable enough to withstand forces during loading, unloading, and transit without tearing or breaking, which minimizes losses. With the growing emphasis on sustainable packaging, biodegradable or recyclable net materials are also being explored. Overall, agricultural packaging nets provide strength, stability, and economy while ensuring safe delivery of farm products from field to market.

Animal Husbandry

Agrotextiles play a significant role in modern animal husbandry by improving animal care, hygiene, and productivity. **Nylon and polyester identification belts** are commonly used on cows for easy recognition and management within large herds. To provide physical support and reduce strain, textile nets are employed to support large udders, especially in high-yielding dairy animals. In automated milking systems, **nonwoven fabrics** serve as efficient filters, ensuring clean milk by removing impurities without affecting quality. Additionally, nonwoven fabrics are widely used as **underlays on cattle paths and trails**, where they help reduce mud formation, improve drainage, and provide stable footing for animals, thus preventing injuries and infections. These textile applications not only enhance animal comfort but also contribute to higher efficiency in dairy and livestock management. By combining durability, hygiene, and practicality, agrotextiles have become an essential component in the sustainable development of animal husbandry practices.

REFERENCES

- Kopitar, D., Marasovic, M., Pahulje, T., & Brnardić, I. (2022). Biodegradable nonwoven agrotextile and films—A review. *Polymers, 14*(11), 2272. https://doi.org/10.3390/polym14112272
- Abidi, N., Rana, D., Chaouch, M., & Bessadok, A. (2021). Accelerated weathering of textile waste nonwovens used as sustainable agricultural mulching. *Journal of Industrial Textiles, 51*(5), 6652–6675. https://doi.org/10.1177/1528083719855326
- Hazarika, A., & Kalita, R. (2024). Development of nonwoven fabric using textile waste and its characterization. *The Journal of Rural and Agricultural Research, 24*(1), 32–38. Retrieved from https://ebook.icar.gov.in/index.php/TJRA/article/view/160074
- Market Research Intellect. (2024). Weaving the future—Top 5 trends in the agrotextiles market. *Market Research Intellect Blog*. Retrieved from https://www.marketresearchintellect.com/blog/weaving-the-future-top-5-trends-in-the-agrotextiles-market
- Choudhary, V., Sharma, R., Chandrashekhar, K., & Pramanik, P. (2025). A review of applications, effects, and potential of mulching technology in agriculture. *International Journal of Agronomy and Agricultural Research, 8*(5S), 45–56. Retrieved from https://www.agronomyjournals.com/special-issue/2025.v8.i5S.2875
- Devi, S., Verma, M., Vaishali, & Anjali. (2025). Enhancing agricultural sustainability: A comprehensive review of agro-textile innovations. *International Journal of Biochemistry Research*, *9*(2), 112–124. Retrieved from https://www.biochemjournal.com/archives/2025.v9.i2.E.3792/enhancing-agricultural-sustainability-a-comprehensive-review-of-agro-textile-innovations
- Agriweb. (2007). Crop protection boosts agrotextiles market: Technical textiles. *New Cloth Market, 21*(7), 43–48.
- Basu, S. K. (2011). Agricultural & horticultural applications of textiles. *The Indian Textile Journal*, *122*(12), 141–148.
- Paul, P., Sanyal, P., & Gon, D. (2012). Application of natural fibres in agrotextiles. *The Indian Textile Journal, 122*(12), 73–78.
- Sakthivel, S., Karthikeyan, L., & Balaselvam, K. (2009). Applications of agro textiles. *The Textile Industry & Trade Journal, 47*(10–12), 15–17.

- Subramaniam, V., Poongodi, G. R., & Sindhuja, V. V. (2009). Agro-textiles: Production, properties & potential. *The Indian Textile Journal*, *119*(7), 73–77.
- Fashion Arun. (n.d.). *Agricultural textiles*. Retrieved from http://fashionarun.page.tl/AGRICULTURAL-TEXTILES.htm
- Textile Learner. (2012, February). *Agro textiles: General property*. Retrieved from http://textilelearner.blogspot.in/2012/02/agro-textiles-general-property.html
- BCH India. (n.d.). *Agro-textiles*. Retrieved from http://www.bch.in/agro-textiles.html
- Fibre2Fashion. (n.d.). *Agro-textiles: A review*. Retrieved from http://www.fibre2fashion.com/industry-article/32/3158/agro-textiles-a-review1.asp
- Fibre2Fashion. (n.d.). *Agro-textiles: A rising wave*. Retrieved from http://www.fibre2fashion.com/industry-article/textile-industry-articles/agro-textiles-a-rising-wave/agro-textiles-a-rising-wave8.asp
- Fibre2Fashion. (n.d.). *Technical textiles*. Retrieved from http://www.fibre2fashion.com/industry-article/textile-industry-articles/technical-textiles/technical-textiles5.asp
- Indian Textile Journal. (n.d.). *Agro-textiles: FA details (1999)*. Retrieved from http://www.indiantextilejournal.com/articles/FAdetails.asp?id=1999
- Indian Textile Journal. (n.d.). *Agro-textiles: FA details (4709)*. Retrieved from http://www.indiantextilejournal.com/articles/FAdetails.asp?id=4709
- Seeger, G. (n.d.). *Geotextiles* [PDF]. STFI Workshop. Retrieved from http://www.t-pot.eu/docs/Workshops/STFI_02_Seeger_Geotextiles.pdf
- DRANCHANE. (n.d.). *Standards on Agrotech presentation*.
- SASMIRA-RIICO. (n.d.). *Agro presentation-1*.

Natural Farming: A promising Approach for Agriculture

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Introduction

The present generation of human beings is enjoying the plentiful reimbursement from prosperity through economic development and scientific advancement in agriculture. Modern intensive farming has played a vital role in increasing the crops' productivity viz., 109% for rice, 208% for wheat, 157% for maize, 78% for potatoes, and 36% for cassava which helped to feed the exploding population and to overcome the crisis of food deficits (Wiebe *et al.,* 2021). Such expansion in food production and economic growth trigger a greater threat to the natural environment. As conventional agriculture is mainly dependent on synthetic chemicals and petrol energy, the excessive use of chemical fertilizers and pesticides has caused environmental pollution and degradation, impair food safety and quality, and posed an adverse effect on human and animal health. This has adversely impacted the crop response ratio and created an imbalance of nutrients in the soil. The crop response ratio has reduced from 58 percent in the last six decades. The ideal ratio of the three major plant nutrients viz., Nitrogen, phosphorus, and Potassium of 4:2:1 is disrupted. Further, it has greatly increased the quantity of greenhouse gases in the environment. Besides, it causes an unstable production with an unsustainable agro ecosystem. Increased farmer indebtedness due to costly agricultural inputs like chemical fertilizers, pesticides, and herbicides, increased cultivation cost with low farm produce prices; have aggravated the country's farm crisis. The concerns of such problems against the environmental and agricultural sustainability in the country prompted the scientists and policymakers to seek appropriate alternative strategies to ensure more sustainable food production with a pollution-free environment.

Current Scenario of Natural Farming in India

There are several states practicing Natural Farming. Major among them are Andhra Pradesh, Chhattisgarh, Kerala, Gujarat, Himachal Pradesh, Jharkhand, Odisha, Madhya Pradesh, Rajasthan, Uttar Pradesh and Tamil Nadu. Till now 6.5 lakh hectare area is covered under natural farming in India. State governments of different states are promoting natural farming through various schemes.

Andhra Pradesh

The Government of Andhra Pradesh turned to farming approaches that are in harmony with nature, as they build on ecological science, rather than input economics. By improving the ecological conditions in each and every site, it is witnessed that Natural Farming reduces the need for synthetic inputs and deliver instead a form of farming that costs less, in financial terms, and is climate resilient.

The Andhra Pradesh Community-Managed Natural Farming (APCNF)

This programme is being implemented by Rythu Sadhikara Samstha (RySS), a not-for-profit company established by the Department of Agriculture, Government of Andhra Pradesh. RySS's mandate is to plan and implement programmes for the empowerment and all-round welfare of farmers.

Gujarat

In Budget 2020–21, special financial assistance was announce for promoting Natural Farming practices under the Gujarat Atma Nirbhar package. Further, on 17 September 2020, two schemes were launched—Sat Pagla Khedut Kalyaan and Pagala for Natural Farming—by the Government of Gujarat.

Himachal Pradesh

Himachal Pradesh practices Natural Farming under the Prakritik Kheti Khushhal Kissan (PK3) Yojana. The scheme aims to reduce the cost of cultivation and enhance farmers' profits. The scheme was announce by the Chief Minister in the Budget speech of 2018–19. The scheme seeks to promote the production of food grains, vegetables, and fruits without the use of synthetic chemicals/pesticides and fertilizers.

Rajasthan

Honorable Chief Minister of Rajasthan during the budget speech of FY2019-20 declared support to natural farming to reduce input costs with a view to empower farmers through remunerative agriculture – Kheti Mein Jaan Toh Sashakt Kisan. The scheme in the form of a pilot project was initiated in three districts of the State viz. Tonk, Sirohi and Banswada. Under the scheme, 18,313 farmers were trained in a two-day long workshop conducted by master-trainers of the Department.

What is Natural Farming?

In the Indian situation, natural farming is a local low-input climate-resilient farming system that advocates the complete exclusion of synthetic chemical agro-inputs. Instead, it encourages farmers to use low-cost, locally sourced inputs such as natural mixtures made using cow dung, cow urine, jaggery, pulse flour, mulch, crop covers, and symbiotic intercropping to stimulate the soil's microbial activities. It emphasizes the enhancement of soil conditions through improved organic matter and biological activity; crop diversification; enhanced biomass recycling with enrich biological interactions in the farm. Natural farming allows for a wide range of agro ecological practices - composting, mulching, green manuring, crop rotations, intercropping, tree intercropping, livestock integration - and takes a holistic approach to farming systems. A set of principle, guides the natural farming as: (i) the farm should be based on poly-cropping, where trees are integrated with various arable and perennial crops; (ii) No synthetic agro-inputs (fertilizers, pesticides, or herbicides) should be applied; (iii) soil should remain covered at all times and for the entire year using cover crops or mulch; (iv) local seeds, which are less costly and more resilient than hybrids, should be used; (v) bio-stimulants, should be used as a catalyst agent to enhance microbial activities of the soil, and botanical extracts for pest management; (vi) minimal tillage; and (vii) integration of livestock with crops for biological and economic synergies.The top states encouraging natural farming are Andhra Pradesh, Himachal Pradesh, and Gujarat. Other States like Uttar Pradesh, Madhya Pradesh, Odisha, Chhattisgarh, Himachal Pradesh, Jharkhand and Tamil Nadu are also practicing this type of farming (Figure 1). Central government launched a natural farming promotion scheme during 2020-21; Bharatiya Prakritik Krishi Paddhati (BPKP) a sub scheme under PKVY. Nearly 6.1 lakh ha has been covered in above said states with total fund of 49.8 crore. There are many opportunities for starting natural farming in our nation because of the varied agro-climates and the richness of farmers' traditional knowledge (Kumar *et al.,* 2019).

Features of natural farming

1. Nutrient uptake from air and sunlight: Natural farming practices hold that plants obtain 98% of their nutrients from the air, water, and sunlight, with only 2% coming from the soil, emphasizing the importance of healthy soil with beneficial microorganisms.

2. Organic mulch for soil health: Continuous soil coverage with organic mulch is essential in natural farming. This practice generates humus and fosters the development of beneficial microorganisms.

3. Bio-cultures instead of fertilizers: Instead of conventional fertilizers, natural farming employs farm made bio-cultures like Jeevamrit and Beejamrit, crafted from indigenous cow breed cow manure and urine, to enhance the micro flora in the soil.

4. Environmental and economic benefits: Natural farming has the potential to increase farmers' income while offering numerous advantages, including mitigating greenhouse gas emissions, restore soil fertility, and promote environmental health.

5. Dependence on Indian breed Cows: The process relies on cow dung and cow urine (Gomutra) obtained from cows of Indian breeds, particularly the Desi cow, which possesses a microbiologically favorable composition**.**

6. Exclusion of exogenous fertilizers: Natural farming refrains from using any chemical or organic exogenous fertilizers in both the soil and on the crops.

7. Encouragement of soil Microbes and earthworms: Natural farming encourages the activity of earthworms and bacteria to decompose organic materials on the soil surface, gradually enriching the soil with nutrients.

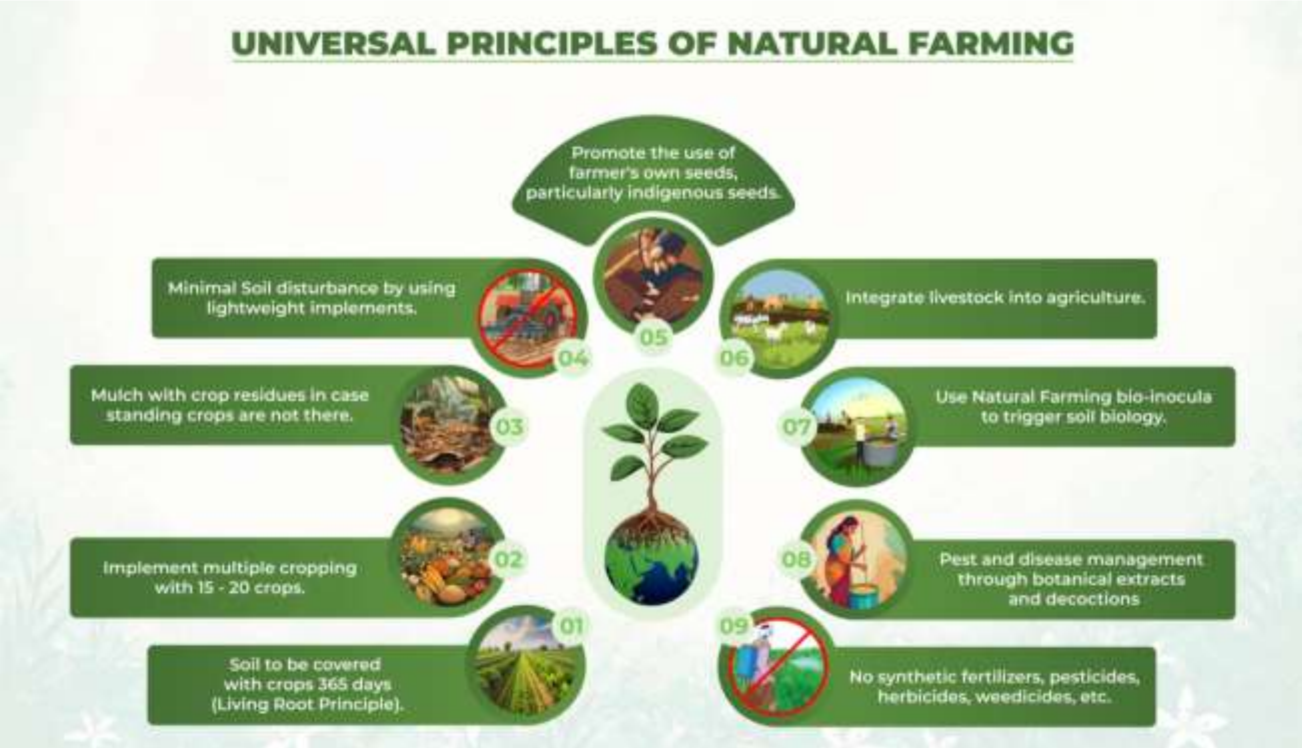
8. Natural weeding Practices: Weeding in natural farming mimics the processes found in natural ecosystems and avoid the use of fertilizers, ploughing, or soil disturbance.

9. Natural pest control: To combat pests and diseases, natural farming utilizes natural insecticides like Dashparni Ark and Neemastra.

10. Role of weeds as mulch: Weeds are intentionally employed as live or dead mulch layers and are considered essential for maintain the ecological balance.

11. Emphasis on multiple cropping: Natural farming advocates for multiple cropping over monoculture, which enhances biodiversity and contributes to soil health.

Principles of Natural Farming



These principles focus on minimizing human involvement while enhancing the natural processes that support plant growth and biodiversity.

1. **No Chemical Inputs**

Unlike conventional agriculture, natural farming eliminates synthetic fertilizers and pesticides, relying instead on natural soil fertility and pest control mechanisms. Farmers use compost, manure, biochar and microbial solutions to maintain soil health, ensure that plants receive essential nutrients without harm the environment.

2. **No Tillage**

The soil is undisturbed, preserving its natural structure, microbial life, and organic matter. Tillage disrupts the soil's ecosystem, leading to erosion and loss of fertility. By avoiding plowing, natural farming encourages earthworms and beneficial microbes to thrive, improving soil aeration and nutrient cycling.

3. **Diverse Crop Cultivation**

Farmers grow multiple plant species together to enhance biodiversity, improve soil health, and reduce pest infestations. Intercropping and crop rotation reduce the risk of monoculture-related diseases and ensure a balanced distribution of nutrients in the soil.

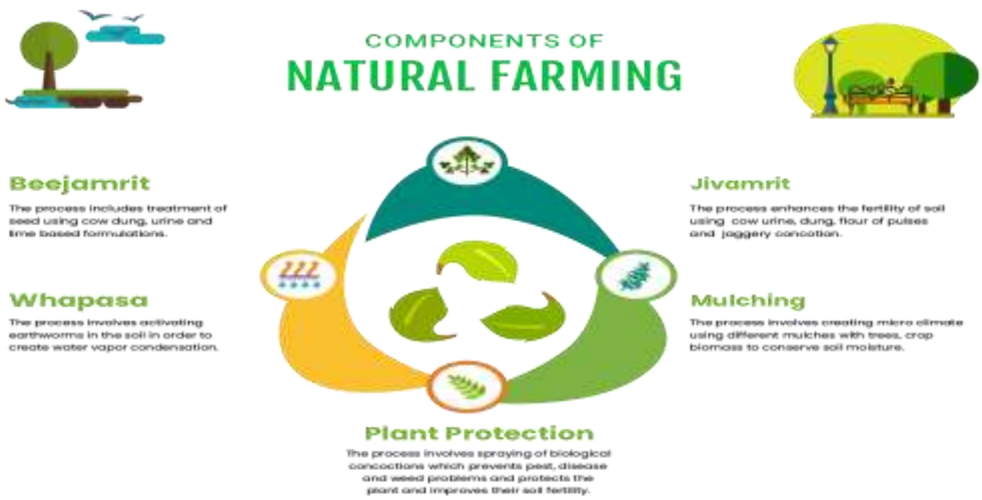
4. Minimal Water Usage

Natural farming techniques optimize water retention in soil, reducing dependence on irrigation. Methods such as mulching and cover cropping help retain moisture, reducing the need for excessive watering. Rainwater harvesting and moisture-preserving techniques ensure crops receive sufficient hydration without wastage.

5. Use of Indigenous Microorganisms (IMOs)

Beneficial microbes and decomposers enhance soil fertility and plant resilience naturally. These microorganisms break down organic matter into essential nutrients, making them readily available to plants. Farmers often cultivate IMOs from local environments to maintain ecological harmony.

Components of natural farming



1. Jivamrita/jeevamrutha: It is a beneficial organic biostimulant made by fermenting well-rotted cow dung, cow urine, jaggery, and water for around 48 hours. This nutrient-rich liquid fertilizer enhances soil fertility, stimulates microbial activity, and aids plant nutrient absorption, contributing to sustainable agriculture by reducing the need for synthetic inputs.

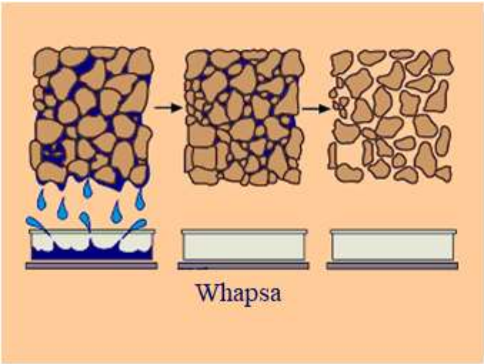
2. Bijamrita/Beejamrutha: Bijamrita is a natural seed treatment solution for crops, prepared by soaking seeds in a mixture of cow dung, water, and lime and cow urine. After soaking, the seeds are dried and then sown. This traditional practice is believed to enhance seed germination, defend against diseases, and promote healthy plant growth in an organic and sustainable manner.

3. Acchadana – Mulching: Subhash Palekar suggests the following types of mulching:

a) Soil Mulch: Preserves topsoil during farming and refrain from tilling it. Moreover, it helps the soil retain water and aerate. Palekar has recommended against deep ploughing.

b) Straw Mulch: The dried biomass waste from earlier crops is hinted to by the straw particles. As Palekar indicates, this could consist of the decomposing remains of any living thing, including plants, animals, etc.

4. Live Mulch (symbiotic intercrops and mixed crops): To give the necessary elements to the soil and crops, Palekar suggests that it is crucial to construct various cropping patterns of monocotyledons and dicotyledons cultivated in the same area.



5. Whapasa – Moisture: Palekar disputes the widespread notion that plant roots require a lot of water. He challenges the over-reliance on irrigation in green revolution farming in this way. He firmly believes that water vapour is essential for the roots. He refers to this as Whapasa, the state in which air and water molecules are present in the soil. He stresses using irrigation just at midday and promotes cutting back on its use.

6. Plant protection measures: Natural farming emphasizes the use of traditional, organic, and plant-based solutions for pest and disease management. Different "astras" or botanical preparations are utilized for plant protection.

a) Neemastra: It is used to eradicate insects or larvae that consume plant foliage and drink plant sap, as well as to prevent or treat diseases. In addition, this aids in preventing the spread of dangerous insects. Neemastra is a bio insecticide and pest deterrent for natural farming that is very simple to manufacture.

b) Agniastra: Neem leaf pulp, tobacco powder, green chilli powder, garlic paste, and turmeric powder are combined to create a natural insecticide. All sucking pests and caterpillars, such as Leaf Roller, Stem Borer, Fruit Borer, and Pod Borer, are controlled with it.

c) Brahmastra: This all-natural insecticide is made from neem, karanj, custard apple, and daphnia leaves, which contain certain alkaloids that deter pests. All sucking pests and concealed caterpillars found in fruit pods are managed by it.

d) Dashaparni ark: It serves as an substitute to Agniastra, Bramhastra, and Neemastra. Depending on what's available, it's made with tobacco powder, ginger paste, turmeric powder, Asafoetida, chilli pulp, garlic paste, and any ten leaves. We can utilise the leaves of several plants, such as neem, pogoamia pinnata, *Annona sqamosa*, Castor, Datura, Rui, Hibiscus, mango, *lantana camara* and guava. Depending on the extent of the infestation, it is used to control various kinds of pests.

e) Fungicide: It is made with cow milk and curd which is found to be very successful in controlling and managing fungal infection.

Importance of Natural Farming

There is an urgent need to increase 60-70% food production to feed the probable 10 billion strong populations of 2050. At present, the focus is not just on increasing crop yields, but also on being environmentally conscious in the process. Climate change is considered a major threat to agricultural production affecting the crops' productivity and environment. After the COVID pandemic, health matters a lot, and the consumers too are more aware of what they eat, going back to the old remedy and natural methods. Hence, today's focus is on providing widespread sustainable solutions to the humankind through balancing farming practice namely natural farming, which gains popular in agriculture. Numerous studies have shown that natural farming is more productive, sustainable, water-efficient, and better for the ecology of farms and the soil. It is regard as a profitable agricultural method with the potential to boost employment and rural development (Devarinti, 2016; Tiwari & Raj, 2020)

Natural farming seeks to address food hunger, farmer distress, health issues brought on by pesticide and fertilizer residue in food and water, global warming, climate change, and natural disaster. In addition, it may provide jobs, which would stop young people from rural areas from moving. As the name implies, natural farming is the art, practice, and science of working with nature to accomplish much more with less.

In addition, the following facts also support the importance of natural farming and its practice in India:

Ecological balance: With increasing concerns about environmental degradation, natural farming is essential to maintain and restore ecological balance by prioritizing biodiversity and healthy ecosystems.

Sustainable agriculture: For agriculture to be sustainable in the long run, we need farming practices that don't reduce the earth's resources. Natural farming emphasize such regenerative practices.

Health implications: The rising health issues related with chemical residues in food highlight the importance of natural farming practices that ensure food safety and nutrition.

Resilience in changing climate: With the unpredictability brought about by climate change, natural farming build resilience in crops and soil due to its inbuilt biodiversity and holistic approach.

Cultural and traditional preservation: Natural farming often integrates indigenous knowledge and practices, ensuring the preservation and continuance of precious traditional wisdom.

Scope of Natural Farming

Natural farming, with its emphasis on sustainable and eco-friendly practices, holds significant promise for the future of agriculture and its role in a balanced ecosystem. The scope of natural farming extends far beyond just the fields, offering numerous advantages across various dimensions.

1. Environmental scope

Soil health: Natural farming techniques improve the soil health through enhancing the organic matter in soil, promoting microbial activity and improving soil structure.

Biodiversity: By avoiding monocultures and chemicals, natural farming supports a various range of flora and fauna, thus maintaining a diversified agro-ecosystem.

Water conservation: With practices like mulching and no-till farming, there's a significant reduction in water evaporation, promoting efficient water use.

Reduced pollution: Non-addition of synthetic chemicals in natural farming helps in maintaining the cleanliness of water bodies including groundwater without pollution.

2. Economic scope

Cost efficiency: Natural farming often requires very fewer external inputs, thus reducing the production costs towards fertilizers, pesticides, other chemicals and machinery.

Premium pricing: Produce cultivated through natural farming can often obtain higher prices in niche markets and among health-conscious consumers.

Resilience: With varied cropping and natural resilience building, natural farming can better handle market fluctuations and crop failures.

3. Health scope

Nutrient rich produce: Crops grown in naturally nourish soil often possess a richer nutrient profile.

Reduced chemical residues: The avoidance of synthetic chemicals means lesser residues on food, approaching towards safer consumption.

4. Social Scope

Empowered communities: As natural farming leans on traditional knowledge, it empowers local communities and encourages collaborative efforts.

Connection with nature: Natural farming promotes a deepened connection between farmers, consumers, and the earth, fostering respect for the environment.

5. Innovation and research scope

New techniques: As the demand for natural farming grows, there is increasing research on refining techniques, discovering new practices, and integrate traditional knowledge with the modern science.

Technological aids: Modern technologies of digital agriculture can be employed to support natural farming, right from apps that aid in pest identification to tools that help monitor soil/ crop health and quality.

6. Global scope

Climate change mitigation: With its potential for carbon sequestration, natural farming can play a role in global efforts to combat climate change.

Sustainable Development Goals: Natural farming aligns well with several United Nations Sustainable Development Goals, including good health and wellbeing, responsible consumption and production, climate action, life on land, and clean water and sanitation.

Benefits of Natural Farming

Yield Improvement

Natural farming increases crop yields by taking maximum use of available labour, soil and equipment. It keeps away the need for chemical inputs like fertilizers, herbicides and pesticides.

Healthy Soil

Various natural inoculants in natural farming lead to the fast build-up of soil micro biota and soil aeration. Jeevamrit helps to improve organic matter and stimulate microbial activity in the soil. Beejamrit treats the seed and alleviates in protecting seedlings from soil-borne diseases and young roots from the fungus. Mulching improves humus formation through enhanced decomposition activity in the soil.

Conservation

Agricultural activities produce the largest share of global methane and nitrous oxide emissions. The use of fertilizers in conventional farming is a major contributor to global greenhouse gas emissions. Natural farming works on an agro-ecology structure and does not rely on chemical fertilizers and pesticides at all thus conserve the environment from harmful and toxic gases.

Resiliency Enhancement

Climate change can be felt throughout the world in the form of droughts, heat waves, and flooding. Crops grown under natural farming have shown greater resilience in the face of these conditions. This is mainly due to the enhanced soil and plant variety. A report by CEEW ("Zero Budget Natural Farming for the Sustainable Development Goals Andhra Pradesh, India") showed that paddy crops withstood the winds and water-logging brought on by the cyclonic winds at Vishakhapatnam in the year 2017. The crops cultivated through natural farming also weathered the Pethai and Titli cyclones of 2018 in much better condition than conventionally cultivated crops. Reduction of Water Consumption 70% of the total accessible freshwater in the world is used for agricultural purposes. In India, groundwater is used for irrigating 60% of the total irrigated area. The natural farming is popular for minimal water consumption and has been shown to improve the water retention capacity of the soil too. This ultimately impacts groundwater reserves.

Native livestock sustainability

Cow dung and urine are used widely to create the natural fertilizers (Jeevamrit and Beejamrit), herbicides, and pesticides required in natural farming. Most farmers who take up natural farming rely on manure and urine from indigenous cows rather than crossbred cows, bullocks, and buffaloes. The growing trend can revive the livestock sector in India

Hike of farmer's income

Natural farming reduces the cost of farming towards the purchase of chemical farm inputs or irrigation. Farmers prepare concoctions of essential plant fertilizers and pesticides with easily available local materials. Irrigation costs are cut down with natural farming. The practice of Whapasa and mulching in natural farming helps to raise the humus content in soil, thus increasing the soil aeration and intern the soil moisture retention benefitting the crops growth without any stress. All these ultimately contribute to more profits.

Farmer's health Improvement

In conventional farming, the use of pesticides and fertilizers can be toxic not just to the crops, but to the person applying it too. Farmers exposed to high levels of chemicals increase the occurrence of non-communicable diseases like chronic neurotoxicity, respiratory illnesses, and even cancer. Natural farming replaces the chemical inputs with natural ones that do not harm the health of the farmer or the community in any way.

Conclusion

Natural farming is currently seeing increased interest and appreciation due to its potential advantages in India. Natural farming presents a possible substitute to traditional farming as farmers deal with issues including moving back soil fertility, water shortages, and environmental degradation. Natural farming is becoming the most promise alternative among both farmers and customers due to its concentration on organic practices, restricted use of external inputs, and attention to maintaining ecological balance. Farmers now have the chance to return from the growing demand for organic food in both the local and international markets. Natural farming also has the potential to improve food security, enhance sustainable agriculture, and resolve vital environmental problems.

However, in order for natural farming in India to reach its full potential, several issues must be addressed. These challenges include ensuring that farmers have access to organic inputs, building effective certification and labelling systems, and setting up effective marketing and distribution channels for organic goods. Farmers, governmental organizations, academic institutions, and consumers must work together to realize the potential of natural farming in India. Investments in infrastructural development, capacity building, and research and development may help natural farming practices extend across the nation.

References:

1. Biswas S, Pakhira R. Natural Farming in India: Concept and Current Scenario. Vigyan Varta. 2023;4(9):76-79.

2. Devarinti, S. R. 2016. Natural farming: eco-friendly and sustainable. Agrotechnology, 5, 147.

3. FAI. 2020. Fertiliser Statistics 2019-20, 65thEdition. The Fertiliser Association of India, New Delhi.

4. Kumar, R., Kumar, S., Yashavanth, B. S., & Meena, P. C. 2019. Natural Farming practices in India: Its adoption and impact on crop yield and farmers' income. Indian J Agric Econ, 74, 420-432.

5. NITI Aayog, 2023, Natural Farming, https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1705191.

6. Sarma, Harsha Hridesh., Paul, Akash., Das, Olympica., Goswami, Anwesha., Hazarika, Priyanka., Borkotoky, Bipasha and Sonowal, Siranjib (2023). The ABCs of natural farming: Principles, components and features: A review. The Pharma Innovation Journal 2023; SP-12(11): 564-568

7. Suman Bery, Ramesh Chand, B.V.R. Subrahmanyam, Neelam Patel. 2023. Natural farming, https://naturalfarming.niti.gov.in/

8. Tiwari, A., & Raj, S. 2020. Natural farming: A game changer in the Era of social, economical and ecological crisis. MANAGE. 64p.

9. Wiebe, K., Sulser, T. B., Dunston, S., Rosegrant, M. W., Fuglie, K., Willenbockel, D., & Nelson, G. C. (2021). Modeling impacts of faster productivity growth to inform the CGIAR initiative on Crops to End Hunger. PloS one, 16(4), e0249994.

Urban Vertical Farming and Smart Technologies: A Pathway to Sustainable Food Systems in India

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Abstract

Urbanization, climate variability, and the increasing demand for food are intensifying pressure on conventional agriculture. Urban vertical farming (UVF), as part of Controlled Environment Agriculture (CEA), offers innovative pathways to address land scarcity, food security, and sustainability challenges. This chapter explores the evolution, systems, and technologies of vertical farming, with a particular focus on the Indian context. The integration of hydroponics, aeroponics, and soil-based vertical racks is examined alongside cost feasibility for Indian farmers. The chapter further discusses the integration of artificial intelligence (AI), Internet of Things (IoT), robotics, and renewable energy into vertical farming ecosystems. Case studies on spinach, strawberry, and cherry tomato highlight practical crop-specific approaches, management practices, and profitability. The chapter concludes by emphasizing the potential of UVF to transform food systems in India while addressing its limitations and the need for supportive policies.

1. Introduction

The global food system is under immense strain due to rapid urbanization, climate change, resource depletion, and population growth. By 2050, the world's population is projected to surpass 10 billion, with nearly 68% residing in urban areas (FAO, 2022). Traditional agriculture, heavily dependent on arable land and freshwater, faces challenges of declining soil fertility, water scarcity, and vulnerability to climate extremes. Urban vertical farming (UVF), a subset of Controlled Environment Agriculture (CEA), represents a paradigm shift in food production. By enabling intensive, year-round cultivation of crops in vertically stacked layers within controlled environments, UVF maximizes space, minimizes water use, and reduces dependence on pesticides. Globally, vertical farms have emerged in regions such as Japan, the United States, Singapore, and the Middle East, demonstrating the potential of this approach to produce safe, high-quality food near consumers.

In India, where urbanization is accelerating and arable land per capita is shrinking, vertical farming offers a unique opportunity to link urban food demand with sustainable production models. The integration of advanced technologies such as AI, IoT, and renewable energy further enhances the efficiency and viability of these systems. This chapter provides a comprehensive analysis of UVF systems, their adoption potential in India, technological enablers, crop-specific models, and socio-economic impacts.

2. Evolution and Scope of Vertical Farming

2.1 Historical background

The modern concept of vertical farming is attributed to Dickson Despommier in the late 1990s, who envisioned skyscrapers dedicated to food production (Despommier, 2010). While large-scale vertical farming skyscrapers remain limited, modular plant factories and warehouse-based systems have proliferated across developed and emerging economies.

2.2 Global adoption trends

- **Japan** pioneered vertical plant factories with artificial lighting (PFALs), focusing on leafy vegetables such as lettuce.
- **Singapore** invested in high-rise farms to reduce dependency on food imports.
- **United States** hosts commercial vertical farms such as AeroFarms and Plenty, emphasizing sustainable, pesticide-free produce.
- **Middle East** has integrated vertical farms into desert environments to overcome aridity.

2.3 Indian scenario

In India, vertical farming is still nascent, mostly limited to startups, research projects, and urban enthusiasts. However, its scope is growing due to:

- Increasing middle-class demand for safe, residue-free produce.
- Government programs encouraging protected cultivation and hydroponics.
- Urban infrastructure that can support rooftop and modular farming systems.

3. Types of Urban Vertical Farming Systems

3.1 Hydroponics (water-based systems)

Hydroponics involves growing plants in nutrient-enriched water without soil.

- **Techniques**: Nutrient Film Technique (NFT), Deep Water Culture (DWC), and drip irrigation.
- **Advantages**: Up to 90% water savings, faster growth cycles, high density production.

- **Suitability**: Leafy vegetables, herbs, tomatoes, cucumbers.

3.2 Aeroponics (mist-based systems)

Aeroponics suspends plant roots in air and periodically mists them with nutrient-rich solutions.

- **Advantages**: Maximum oxygen availability, faster nutrient absorption, up to 95% water savings.
- **Challenges**: High technical demand, higher upfront cost, risk of system failure if misting stops.
- **Suitability**: High-value crops like strawberries, lettuce, medicinal herbs.

3.3 Soil-based vertical racks

These systems use lightweight soil or substrates in vertical structures such as racks, grow-bags, or wall-mounted planters.

- **Advantages**: Low cost, simpler technology, easier adoption for small-scale Indian farmers.
- **Limitations**: Less water-efficient than hydroponics, slower growth cycles, risk of soil-borne pests.

3.4 Comparative analysis

- Hydroponics: best for commercial scale.
- Aeroponics: best for high-value, research-driven or niche farming.
- Soil racks: best for smallholder adoption and low investment urban setups.

4. Economic Feasibility for Indian Farmers

4.1 Cost per unit

- **Hydroponic NFT unit (50 m²)**: ₹3–4 lakhs (basic setup with nutrient tanks, channels, pumps).
- **Aeroponic tower (10–15 plants per tower)**: ₹2,000–3,000 per tower; a small farm of 100 towers costs ~₹2.5–3 lakhs.
- **Soil-based vertical rack (5-tier, 20 sq. ft)**: ₹2,000–5,000 depending on material (PVC/metal).

4.2 Returns

- Leafy vegetables (spinach, lettuce): 8–10 harvest cycles/year.
- Tomatoes and cucumbers: 3–4 cycles/year, higher market price.
- Strawberries: Premium niche fruit with high urban demand.

4.3 Profitability

Small urban farms can generate **net returns of ₹40,000–60,000 per 100 sq. m annually**, depending on crop choice, marketing, and scale.

4.4 Market linkages

Direct-to-consumer (farmers' markets, online apps), tie-ups with supermarkets, and supplying restaurants provide profitable outlets.

5. Integration of Advanced Technologies

5.1 Artificial Intelligence (AI)

- AI algorithms predict crop growth, optimize nutrient delivery, and detect diseases.
- Machine learning models forecast demand and align production schedules.

5.2 Internet of Things (IoT)

- IoT sensors monitor pH, EC, humidity, light, and CO_2 in real-time.
- Automated controllers adjust irrigation and nutrient supply.

5.3 Robotics and automation

- Robotic arms for seeding, harvesting, and packaging.
- Drones for monitoring plant health in larger greenhouse-integrated vertical farms.

5.4 Renewable energy integration

Solar panels powering LED grow-lights and pumps reduce dependence on grid electricity and improve sustainability.

6. Case Models: Crop-Specific Approaches

6.1 Spinach (Hydroponics NFT system)

- **Growth cycle**: 25–30 days per harvest.
- **Yield**: 3–3.5 kg/m² per cycle.
- **Management**: Maintain pH 5.8–6.2, EC 1.8–2.0.
- **Profitability**: 8–9 cycles annually ensure steady income.

6.2 Strawberry (Aeroponic towers)

- **Growth cycle**: 90–100 days to fruiting.
- **Yield**: 8–10 tons/acre equivalent.
- **Management**: High oxygen requirement, nutrient mist every 5–10 minutes.
- **Profitability**: Sold at premium prices (₹200–300/kg in urban markets).

6.3 Cherry Tomato (Hydroponic drip system)

- **Growth cycle**: 90–110 days.
- **Yield**: 12–14 kg/m².
- **Management**: Requires strong trellising support, nutrient-rich solution (higher potassium).

- **Profitability**: High demand among restaurants and urban consumers.

7. Environmental and Social Impacts

- **Water conservation**: Hydroponics and aeroponics save 85–95% water compared to open-field.
- **Pesticide-free food**: Controlled environments reduce pest attacks.
- **Reduced carbon footprint**: Proximity to urban consumers lowers transport emissions.
- **Employment**: Encourages agri-entrepreneurship among youth.

8. Challenges and Future Prospects

8.1 Challenges

- High initial investment and energy dependency.
- Lack of technical knowledge among Indian farmers.
- Limited awareness of marketing and supply chain linkages.

8.2 Future prospects

- Government support through subsidies and training.
- Increasing role of startups in urban farming models.
- Integration with smart cities and urban planning.

9. Conclusion: Urban vertical farming represents a transformative solution to the challenges of food security, sustainability, and urbanization. By integrating advanced technologies such as AI, IoT, and renewable energy, vertical farming can achieve high productivity, resource efficiency, and economic viability. For Indian farmers, adopting scalable, low-cost vertical farming models presents opportunities for profitability, entrepreneurship, and resilient food production. Policymakers, researchers, and entrepreneurs must collaborate to overcome barriers and promote vertical farming as a mainstream agricultural practice in India.

References

- Alam, M., Rahman, M., & Kumar, R. (2023). Advances in hydroponics and sustainable urban agriculture: Opportunities and challenges. *Journal of Cleaner Production, 398,* 136722. https://doi.org/10.1016/j.jclepro.2023.136722
- Armanda, D. T., Guinée, J. B., & Tukker, A. (2019). The second green revolution: Innovative urban agriculture systems. *Resources, Conservation and Recycling, 147,* 143–156. https://doi.org/10.1016/j.resconrec.2018.05.026
- Benis, K., Reinhart, C., & Ferrão, P. (2017). Building-integrated agriculture (BIA): An

overview of urban rooftop farming systems. *Renewable and Sustainable Energy Reviews, 75,* 1195–1206. https://doi.org/10.1016/j.rser.2016.11.050

- Burritt, R., Christ, K., & Rimmel, G. (2025). Sustainability challenges in vertical farming: Energy and economics. *Agricultural Systems, 212,* 103692. https://doi.org/10.1016/j.agsy.2024.103692
- Clune, S., Crossin, E., & Verghese, K. (2017). Systematic review of greenhouse gas emissions for different fresh food categories. *Journal of Cleaner Production, 140,* 766–783. https://doi.org/10.1016/j.jclepro.2016.04.082
- Despommier, D. (2010). *The vertical farm: Feeding the world in the 21st century.* Thomas Dunne Books.
- Dsouza, R., Patel, V., & Gupta, A. (2023). Socio-economic and environmental impacts of controlled environment agriculture: A systems approach. *Agricultural Systems, 207,* 103614. https://doi.org/10.1016/j.agsy.2023.103614
- Fei, X., Sun, Z., & Zhang, L. (2025). Global trends in indoor farming markets: Energy and efficiency perspectives. *Journal of Agribusiness and Development, 44(2),* 55–71.
- Graamans, L., Baeza, E., van den Dobbelsteen, A., Tsafaras, I., & Stanghellini, C. (2018). Plant factories versus greenhouses: Comparison of resource use efficiency. *Agricultural Systems, 160,* 31–43. https://doi.org/10.1016/j.agsy.2017.11.003
- Gu, B., Zhang, X., & Bai, X. (2021). Urbanization and food security in the 21st century. *Nature Food, 2*(1), 7–13. https://doi.org/10.1038/s43016-020-00294-1
- Kozai, T., Niu, G., & Takagaki, M. (2019). *Plant factory: An indoor vertical farming system for efficient quality food production.* Academic Press.
- Kumar, P., Singh, R., & Yadav, S. (2023). Aeroponics and its potential for sustainable food systems. *Indian Journal of Agricultural Sciences, 93(5),* 877–885.
- Mina, K., Ahmed, S., & Lee, J. (2023). Environmental impacts of global food demand: A scenario analysis. *Science of the Total Environment, 857,* 159330. https://doi.org/10.1016/j.scitotenv.2022.159330
- Rajalakshmi, P., Sharma, A., & Rao, V. (2022). Aquaponics: Closed-loop systems for sustainable farming. *Agricultural Reviews, 43(3),* 324–335. https://doi.org/10.18805/ag.R-2220
- Shamshiri, R. R., et al. (2018). Advances in greenhouse automation and controlled environment agriculture: A review. *Biosystems Engineering, 164,* 93–112. https://doi.org/10.1016/j.biosystemseng.2017.09.011
- Srivastava, P., & Mathur, A. (2023). Hydroponic farming in India: Technologies and profitability. *Current Science, 125(10),* 1576–1585. https://doi.org/10.18520/cs/v125/i10/1576-1585
- Tong, Y., Zhao, Q., & Li, F. (2026). Productivity gains in vertical farming systems: A meta-analysis. *Agricultural Reviews, 48(1),* 12–29.
- Vernon, M., Choudhary, R., & Patel, D. (2023). Optimizing climate control in CEA to improve flavor and nutrition. *Horticultural Science, 58(2),* 245–258. https://doi.org/10.21273/HORTSCI16704-23
- Zarei, M., Taghipour, A., & Fathollahi, M. (2019). Life cycle assessment of greenhouse systems for vegetable production. *Journal of Environmental Management, 241,* 406–414. https://doi.org/10.1016/j.jenvman.2019.04.019
- Zhang, X., & Li, Y. (2019). LED lighting and CO_2 enrichment in vertical farming: Crop yield and sustainability impacts. *Frontiers in Plant Science, 10,* 1196. https://doi.org/10.3389/fpls.2019.01196.

Millets: Source for Fight Nutrition Insecurity and Climate disaster

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Abstract

'Millets' were among the first crops to be domesticated in India with several evidence of its consumption during the Indus valley civilization. Being grown in more than 130 countries at present, Millets are considered traditional food for more than half a billion people across Asia and Africa. In India, millets are primarily a kharif crop, requiring less water and agricultural inputs than other similar staples. Millets are important by the virtue of its mammoth potential to generate livelihoods, increase farmers' income and ensure food & nutritional security all over the world. With respect to states, Chhattisgarh, Mizoram and Rajasthan have been allocated the month of January for carrying out specific activities for sensitization and promotion of IYM. The states will be conducting millet centric activities including Mahotsav's/ melas and food festivals, training of farmers, awareness campaigns, workshops/ seminars, placement of hoardings and distribution of promotional material at various key locations in the state, etc. Other states that are organizing similar activities in the month of January include Maharashtra, Uttarakhand and Punjab.

Key Word: Millets, Climate change, Nutri Cereals, food security.

What are millets ?

Millet is a common term for categorising small-seeded grasses that are often called Nutri-cereals. Some of them are sorghum (jowar), pearl millet (bajra), finger millet (ragi), little millet (kutki), foxtail millet (kakun), proso millet (cheena), barnyard millet (sawa), and kodo millet (kodon).

An essential staple cereal crop for millions of smallholder dryland farmers across Sub-Saharan Africa and Asia, millets offer nutrition, resilience, income and livelihood for farmers, and have multiple uses such as food, feed, fodder, biofuels and brewing.

Fig 1: Nutri-cereals

International Year of Millets (IYM) 2023 kick starts with Focused Activities in India

U.N. Food and Agriculture Organization is endorsing India's proposal to declare 2023 as the International Year of Millets. Millet, a grain mainly grown and consumed in developing countries until recently and once considered a poor man's staple, is quickly becoming a favorite globally among those affected by climate change because of its ability to thrive in harsh and arid environments. Its drought-resistant quality makes it attractive as many parts of the world begin to experience a water supply shortage.

Organizations like the International Crop Research Institute for Semi-Arid Tropics (ICRISAT), are investing in and developing a strand of pearl millet with greater resistance to drought and disease to address climate change and the myriad of new challenges it is presenting. Funding for this project is ensured until 2020 in partnership with The Crop Wild Relative Project, a global organization that collects and conserves the wild relatives of 29 cultivated crops to ensure future crop diversity, and Crop Trust, an international organization dedicated solely to conserving crop diversity.

In addition to millet's attractive growth characteristics, it is one of the most nutritious and anti-allergenic grains available. Millet is gluten-free, making it an excellent choice for the millions of people around the world who suffer from Celiac disease or have a gluten sensitivity. It is high in B vitamins, calcium, iron, potassium, zinc, magnesium, and fats. And it's an excellent source of protein and dietary fiber.

Fig 2: Anti-allergenic Millets

Millet production is projected to sharply increase due to its many health benefits and ability to grow in a variety of climates. At a recent planning meeting to address high levels of malnutrition across India and Africa that included ICRISAT and 50 scientists from public, private, and national systems, Dr. Wolfgang Pfeiffer, Global Director of Product Development and Commercialization for Harvest Plus, asked, "Could high-iron pearl millet be the next superfood in India—the next 'quinoa' for the westernized markets?"

The Government of India sponsored the proposal for International Year of Millets (IYM) 2023 which was accepted by the United Nations General Assembly (UNGA). The declaration has been instrumental for the Government of India to be at the forefront in celebrating the IYM. PM Narendra Modi has also shared his vision to make IYM 2023 a 'People's Movement' alongside positioning India as the 'Global Hub for Millets'. Spearheaded by the Prime Minister, the Government of India sponsored the proposal for International Year of Millets (IYM) 2023 which was accepted by the United Nations General Assembly (UNGA). The declaration has been instrumental for the Government of India to be at the forefront in celebrating the IYM. The PM of India, Shri Narendra Modi has also shared his vision to make IYM 2023 a 'People's Movement' All positioning India as the 'Global Hub for Millets' 'Millets' were among the first crops to be domesticated in India with several evidence of its consumption during the Indus valley civilization. Being grown in more than 130 countries at present, Millets are considered traditional food for more than half a billion people across Asia and Africa. In India, millets are primarily a kharif crop, requiring less water and agricultural inputs than other similar staples. Millets are important by the virtue of its mammoth potential to generate livelihoods, increase farmers' income and ensure food & nutritional security all over the world.

Recognizing the enormous potential of Millets, which also aligns with several UN Sustainable Development Goals (SDGs), the Government of India (GoI) has prioritized Millets. In April 2018, Millets were rebranded as "Nutri Cereals", followed by the year 2018 being declared as the National Year of Millets, aiming at larger promotion and demand generation. The global millets market is projected to register a CAGR of 4.5% during the forecast period between 2021-2026.

On 6th December 2022, the Food and Agriculture Organization (FAO) of the United Nations, organized an opening ceremony for the International Year of Millets – 2023 at Rome, Italy. The event was attended by a delegation of senior government officials from India. Next in the series, prior to the year-long celebration of 'International Year of Millets (IYM) 2023', the Department of Agriculture & Farmers Welfare hosted a special 'Millet Luncheon' for the Members of the Parliament at the Parliament house.

The Department of Agriculture & Farmers Welfare has taken a proactive multi-stakeholder engagement approach (engaging all the central government ministries, states/UTs, farmers, start-ups, exporters, retail businesses, hotels, Indian Embassies etc.) to achieve the aim of IYM 2023 and taking Indian millets globally. Ministries, states and Indian embassies have been focused months in 2023 to carry out various activities for promotion of IYM and increase awareness about benefits of millets for the Consumer, Cultivator and Climate.

Among central ministries, the activities related to IYM for the month of January 2023 will be kick started by the Ministry of Sports and Youth Affairs, Government of India. The ministry has planned 15 activities over 15 days in January which include engaging sports persons, nutritionists and fitness experts through video messages, conducting webinars on millets with leading nutritionists, dieticians and elite athletes, promotion amplification through Fit India App, etc. Some of the other ministries which have planned events in January are Ministry of Food Processing Industries which will be organizing Millet Fair-cum-exhibitions in Andhra Pradesh, Bihar and Madhya Pradesh; FSSAI will organize Eat Right Melas in Punjab, Kerala and Tamil Nadu etc. With respect to states, Chhattisgarh, Mizoram and Rajasthan have been allocated the month of January for carrying out specific activities for sensitization and promotion of IYM. The states will be conducting millet centric activities including mahotsavs/ melas and food festivals, training of farmers, awareness campaigns, workshops/ seminars, placement of hoardings and distribution of promotional material at various key locations in the state, etc. Other states that are organizing similar activities in the month of January include Maharashtra, Uttarakhand and Punjab. During January 2023, Agricultural and Processed Food Products Export Development Authority (APEDA) and DA&FW will be participating in the Trade Show in Belgium wherein a multi-stakeholder delegation with representatives from DA&FW, APEDA, start-ups, exporters and Farmer Producer Organizations (FPOs) will showcase the diversity of Indian millets through RTE and RTC millet-based products marketed by Indian companies, B2B, B2G interactions etc.

Moreover, Embassies of India across more than 140 countries will be participating in celebration of IYM during 2023 by conducting side events on IYM involving the Indian Diaspora through exhibition, seminars, talks, panel discussions, etc. In January, Embassy of India in Azerbaijan and Embassy of India in Belarus will be conducting activities such as B2B meeting with the participation of local chambers, food bloggers, importers of food items and local restaurants etc. Cooked Millets dish exhibitions/ contests will be organized with the help of Indian diaspora and Millets dishes will be served as part of the Republic Day celebrations. The High Commission of India in Abuja and Consulate General of India in Lagos, as part of promotion of IYM, have planned a Millets Food Festival and a Millets Food preparation competition in January 2023. The Millets Food Festival would be held at the High Commission premises and provide stalls for preparation with invitees including both Nigerian dignitaries and India community.

Steps taken for promoting Millets Since 2018

It was in 2018 that the government of India decided to mark the National Year of Millets.

- National Year for Millets 2018 - as Nutri cereals Sorghum (Jowar), Pearl Millet (Bajra), Finger Millet (Ragi/Mandua), Minor Millets i.e. Foxtail Millet (Kangani/Kakun), Proso Millet (Cheena), Kodo Millet (Kodo), Barnyard Millet (Sawa/Sanwa/ Jhangora), Little Millet (Kutki) and two Pseudo Millets (Buck-wheat (Kuttu) and Ameranthus (Chaulai). “Sub Mission on Millets” under National Food Security Mission since 2018 has been started. Several State participating in launched mission on Millets for promoting millet.
- Ministry of Agriculture is the nodal agency and the Indian Institute of Millets Research has been made the nodal institute for the celebration of the International Year of Millets.
- **Food and Agriculture Organisation (FAO):** The aim for 2023 is to increase awareness about millet in food security and nutrition. And also to encourage investments in research and development for the same. India's proposal to observe an International Year of Millets in 2023 was approved by the **Food and Agriculture Organisation (FAO)** in 2018 and the **United**

Nations General Assembly has declared the year 2023 as the International Year of Millets With the support of 72 other countries.

Fig 3: different types of Millets

Aim of the International Year of Millets:

- **Elevate awareness** of the contribution of millet to **food security and nutrition.**
- **Inspire stakeholders** on improving sustainable production and quality of millets.
- **Draw focus on enhanced investment in research** and development and extension services to achieve the other two aims.

Facts/ Data on Millets

- India is the **largest producer of millet in the world.**
- It Accounts for **20 % of global production and 80 % of Asia's production.**
- It is a common term to categorise **small-seeded grasses** that are often termed Nutri-cereals or dryland-cereals and includes **sorghum, pearl millet, ragi, small millet, foxtail millet, proso millet, barnyard millet and Kodo millet, among others.**

Global Distribution of Millets

- **India, Nigeria and China** are the largest producers of millets in the world, accounting for more than 55% of the global production.
- **For many years, India was a major producer of millets**. However, in recent years, millet production has increased dramatically in Africa.

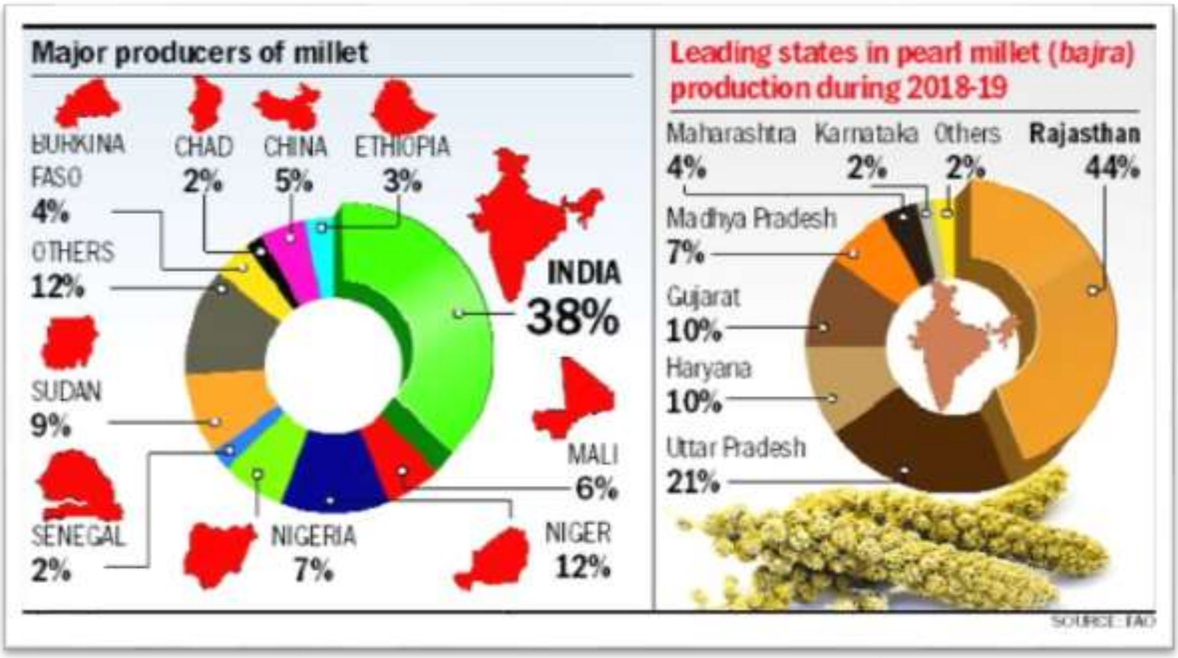

Fig 4: different types of Millets

Significance / Benefits of millets

- Short time and poor soil: The crop does not require much water and gets ready in a short time. Millets do not require high-quality soil to grow and hence can easily cater to the needs of the growing population.
- Superfood: Millets are called the super grain because of their high nutritional value.
- High in fibre: According to the Food Safety and Standards Authority of India (FSSAI) millets are high in dietary fibre.
- Other contents: millet contains 7-12 % protein, 2-5 % fat, 65-75% carbohydrates and 15-20% dietary fibre.
- Alleviating malnutrition: Due to their high density of nutrients including vitamins, minerals, phytochemicals and dietary fibre, millets are also excellent grains to alleviate malnutrition and micronutrient deficiency.
- COVID-19: The nutritional value of millets makes it even more relevant globally in the aftermath of the COVID-19 pandemic.
- Millets can also help in tackling health challenges such as obesity, diabetes and lifestyle problems as they are gluten-free, have a low glycemic index and are high in dietary fibre and antioxidants.

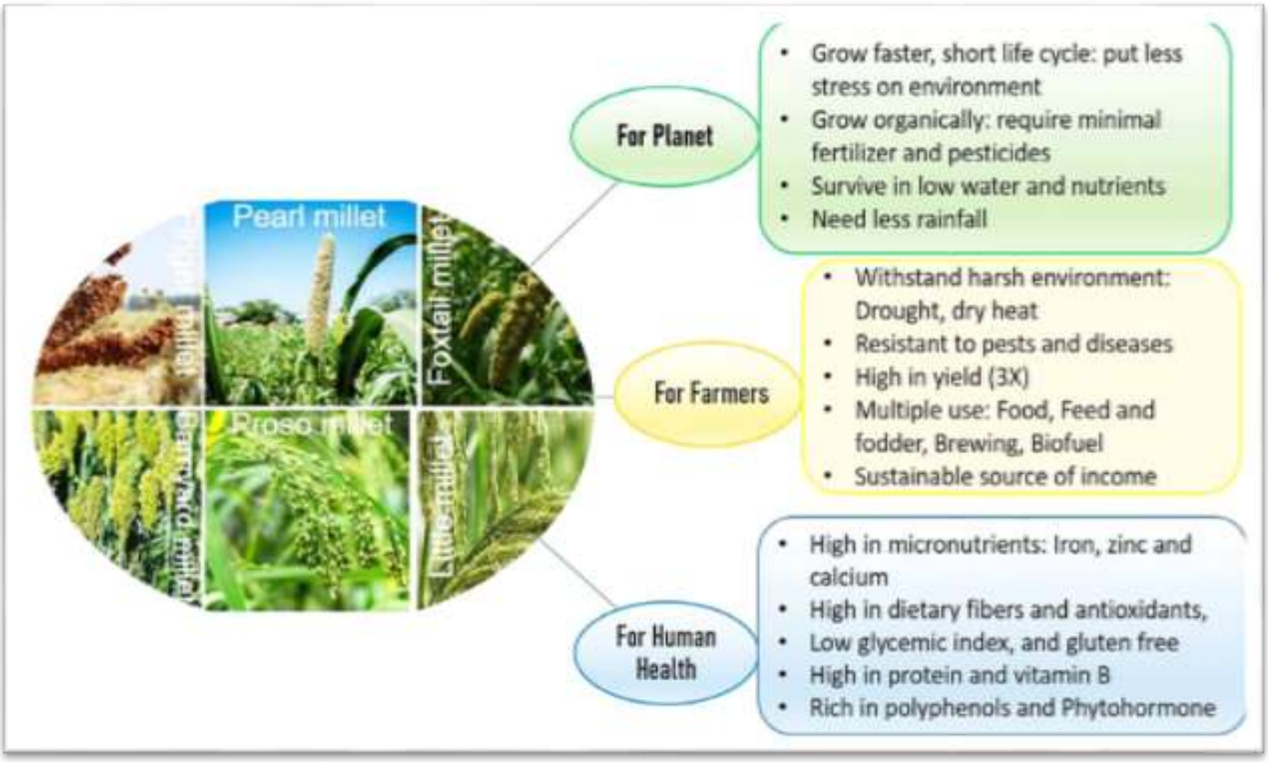

FIG 5: Benefits of millets for climate, Agriculture, Human health, Food and Nutritional Security.

- It can provide nutritional security and protect against nutritional deficiency, especially among children and women.
- It will also be critical for climate change measures in drylands and important for smallholder and marginal farmers.

Concerns /Challenges

- The awareness of the benefits of millets is still low and this is the reason for the lesser number of players working on value-added millet products in India.
- The main reasons behind the decline are low remuneration, lack of input subsidies and price incentives, subsidised supply of fine cereals through the public distribution system (PDS) and change in consumer preferences and lower demand
- The lower demand also means limited supply and higher prices.
- In the absence of proper market linkages for forest and agricultural produce, millet consumption is restricted to rural haats, bazaars, tourist spots and festivals.

Steps taken towards promoting millets

- The Department of Food and Public Distribution (DFPD) has ordered all its offices to introduce and promote millets in their canteens and in meetings.

- Millet Startup Innovation Challenge: Department of Agriculture and Farmers Welfare on the MyGov platform has launched various competitions to raise awareness of the benefits of millets.
- This initiative encourages young minds to offer technological/ business solutions to the existing problems in the millets ecosystem.
- POSHAN Mission Abhiyan: The government also notified millets as nutri-cereals and included them under the POSHAN Mission Abhiyan.
- Mann ki Baat: PM had also highlighted the benefits of Millets to both farmers and consumers in one of the editions of his monthly radio programme 'Mann ki Baat'.
- National Nutri Cereals Convention 4.0: The objective of the convention is to bring together all the stakeholders from Nutri Cereals Industry, from producers to processors to consumers, as well as academicians, researchers, and policymakers.
- Towards this endeavor, through a collaborative approach, the DA&FW urges everyone including the International Organizations, Academia, Hotels, Media, Indian Diaspora, Start-up communities, Civil Society, and all others in the Millets value-chain to come forward and join hands to revive the forgotten glory of 'Miracle Millets' through the grand celebration of International Year of Millets - 2023.
- Millets are also an integral part of the G-20 meetings and delegates will be given a true millet experience through tasting, meeting farmers and interactive sessions with start-ups and FPOs.
- The spirit of the whole of government approach is truly being seen in the celebration of the International Year of Millets 2023.

References

1.Saxena, R., Sai, V., Jin, W., Valérie, O. and Vijaya, R., Millets for food security in the context of climate change: a review. Sustainability, 2018, 10(7), 2228.

2. Saleh, A. S., Zhang, Q., Chen, J. and Shen, Q., Millet grains: nutritional quality, processing, and potential health benefits. Compr. Rev. Food Sci. Food Saf., 2013, 12(3), 281–295.

3. Kaur, P., Purewal, S. S., Sandhu, K. S., Kaur, M. and Salar, R. K., Millets: a cereal grain with potent antioxidants and health benefits. J. Food Meas. Character., 2019, 13(1), 793–806.

4. Kumar, A., Tomer, V., Kaur, A., Kumar, V. and Gupta, K., Millets: a solution to agrarian and nutritional challenges. Agric. Food Security, 2018, 7(1), 31.

5. ICAR-ACRIP, 2018; http://www.aicrpsm.res.in/Downloads/ Reports/ICAR-AICRP%20reports-2017-18/1-Introduction.pdf (accessed on 3 June 2018).

6. Chandra, D., Chandra, S. and Sharma, A. K., Review of finger millet (Eleusine coracana (L.) Gaertn): a power house of health benefiting nutrients. Food Sci. Human Wellness, 2016, 5(3), 149–155.

7. Karuppasamy, P., Malathi, D., Banumathi, P., Varadharaju, N. and Seetharaman, K., Evaluation of quality characteristics of bread from kodo, little and foxtail millets. Int. J. Food Sci., 2012, 2(2), 35–39.

8. Viswanath, V., Urooj, A. and Malleshi, N. G., Evaluation of antioxidant and antimicrobial properties of finger millet polyphenols (Eleusine coracana). Food Chem., 2009, 114(1), 340–346.

9. Panwar, P., Dubey, A. and Verma, A. K., Evaluation of nutraceutical and antinutritional properties in barnyard and finger millet varieties grown in Himalayan region. J. Food Sci. Technol., 2016, 53(6), 2779–2787.

10. Udeh, H. O., Duodu, K. G. and Jideani, A. I., Effect of malting period on physicochemical properties, minerals, and phytic acid of finger millet (Eleusine coracana) flour varieties. Food Sci. Nutr., 2018, 6(7), 1858–1869.

11. Association of Official Analytical Chemists, Official Methods of Analysis, the Association of Official Analytical Chemists (17th edn) (ed. Horwitz, W.), AOAC International, Maryland, USA, 2010.

12. AACC, Approved Methods of the AACC, American Association of Cereal Chemists, St. Paul, USA, 2000, 10th edn.

13. Singleton, V. L. and Rossi, J. A., Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. Am. J. Enol. Viticult., 1965, 16(3), 144–158.

14.www.tribuneindia.com/news/features/resilient-grain-needs-a-fillip-to-gain-ground-234860 (fig-4)

ANAESTHETIC CONSIDERATIONS IN VETERINARY PATIENTS WITH MAJOR SYSTEMIC DISEASES

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Abstract

Veterinarians often encounter cases where animals with major organ diseases which require anaesthesia for surgery, either for procedures unrelated to the liver condition or for interventions necessary to diagnose or treat the underlying disease. Once the decision is made to perform surgery on an animal with major disease, every effort must be taken to stabilise the patient's condition prior to the procedure. Special attention should be given to any pathological changes caused by major disease that could adversely impact anaesthesia and surgical outcomes. When selecting pre-anaesthetic medications and designing the anaesthetic protocol, drugs that rely heavily on hepatic metabolism and elimination should be avoided. It is important to recognise that central nervous system depressants tend to have an exaggerated effect in animals with hepatic dysfunction. Most injectable anaesthetic agents are metabolised and/or eliminated by the liver, whereas modern inhalational anaesthetics undergo minimal hepatic metabolism. Therefore, in high-risk patients with liver disease, the anaesthetic approach should aim to reduce the use of injectable agents and favour inhalational anaesthetics for both induction and maintenance of anaesthesia. Peri-operative analgesia in these patients can be effectively managed using opioids where a constant rate infusion is particularly beneficial or through epidural administration of local anaesthetics and/or preservative-free opioids.

Anaesthesia for patients with hepatic diseases

Liver plays a crucial role in producing clotting factors and albumin, as well as in metabolizing proteins, carbohydrates, and fats. Furthermore, it is responsible for metabolizing a wide range of both endogenous and exogenous substances, including most anesthetic drugs. Therefore, when a patient has liver disease that impairs hepatic function, careful evaluation and preparation are essential before surgery. An anesthetic management plan should be designed to minimize further harm to liver function and to avoid prolonged drug effects due to impaired metabolism.

There are multisystemic signs associated with hepatic insufficiency which include ascites, depression, seizures, jaundice, hepatic encephalopathy, anorexia, and weight loss. Tests of substrate metabolism may give an indication of hepatic function. Low values for albumin, urea nitrogen, glucose, and cholesterol are associated with poor hepatic function. Coagulation defects such as prolonged prothrombin time, prolonged partial thromboplastin time, and in creased fibrinogen values may also indicate decreased hepatic function. Bilirubin is formed by metabolism of degraded hemo-globin by macrophages and carried by albumin to the liver for conjugation to a diglucuronide.

Blood ammonia concentration and retention of dyes such as sulfobromophthalein (BSP) or indocyanine green (ICG) indicate liver dysfunction as evidenced by the liver's inability to eliminate these substances in a normal manner. The dyes, like bile acids, are more sensitive indicators of liver dysfunction than is a change in bilirubin concentration. Bile acids are produced by the liver and excreted in the bile. A marked increase in postprandial bile acid concentration indicates decreased hepatic function or the presence of a portocaval vascular shunt. Tests of cell membrane integrity (i.e., alanine aminotransferase, gamma-glutamyltransferase, sorbitol dehydrogenase, and lactate dehydrogenase) and serum alkaline phosphatase indicate hepatocellular damage but may not reflect altered hepatic function.

Tranquilizers/Sedatives: The use of acepromazine. droperidol, and aradrenergic agonists should be avoided in patients with moderate to severe liver disease. Hypotension may occur after administration of phenothiazine (acepromazine) or butyrophenone (droperidol) tranquilizers because of peripheral vasodilation mediated by a-adrenergic blockade. Phenothiazine administration has also been associated with thrombocytopathy and may exacerbate coagulopathy associated with hepatopathy. Dysrhythmias such as bradycardia or atrioventricular block and alterations of plasma glucose concen-tration may occur after administration of xylazine or detomidine. Diazepam is generally considered safe when used in intravenous doses of less than 0.2 mg/kg because it causes minimal changes in cardiovascular function. However, in animals with severe liver dysfunction, the duration of action of benzodiazepines may be significantly prolonged because of decreased hepatic biotransformation. Diazepam may not consistently tranquilize healthy young animals but frequently produces tranquilization in animals with liver disease.

Opioids: These can be used in patients with liver disease. Morphine and meperidine can cause release of histamine, which may cause hypotension and a decrease in total hepatic blood flow. Respiratory depression from opioids may lead to decreased oxygen delivery to all body tissues, including the liver. Butorphanol and buprenorphine are associated with less respiratory depression than other opioid agonists and may be reasonable choices for patients with hepatic disease when maximal opioid analgesia is not required. Fentanyl, delivered by continuous-rate intravenous infusion, enables rapid individual patient dose titration and is an effective and reasonably safe method for providing opioid analgesia to patients.

Thiobarbiturates: These should be used in low doses or their use avoided in patients with liver disease. A single, intubating dose of thiobarbiturate is not necessarily contraindicated because it will be redistributed from the brain to less well perfused tissues, terminating the anesthetic effect. However, liver disease may affect the duration and depth of thiobarbiturate-induced anesthesia because of increased sensitivity of the central nervous system or hypoalbuminemia and decreased protein binding of the anesthetic. Anesthesia should not be maintained by redosing thiobarbiturates in patients with liver disease. Methohexital is a methylated oxybarbiturate, and although it is more rapidly metabolized than thiobarbiturates, it is associated with excitation and possible seizures during the recovery period.

Propofol: The major advantage of propofol over a thiobarbiturate is the rapid rate of propofol elimination. In dogs, the incidence of apnea immediately after injection seems to be greater than that associated with thiobarbiturates.

Etomidate: Etomidate has a short duration of action, primarily because of rapid redistribution from the brain to muscle tissue. Etomidate does not decrease hepatic perfusion and is metabolized by the hepatic microsomal enzyme system, as well as by plasma esterases. The total body clearance rate for etomidate is five times as fast as for thiopental, although clinically the duration of action is similar after a single dose. Hemolysis appears to be caused by the propylene-glycol vehicle in which etomidate is formulated.

Dissociative anaesthetics: Dissociative anesthetics such as tiletamine (Telazol) or ketamine are generally acceptable for induction of anesthesia in patients with hepatic disease. Intravenous administration is preferred in order to minimize the dose required for tracheal intubation. In dogs, these drugs are largely metabolized by the liver, so maintenance of anesthesia should be with an inhalant. Dissociative anesthetics may induce seizures in dogs or cats. In cats, ketamine is metabolized to a lesser extent by the liver to form norketamine, which has about 10% of the activity of ketamine. Zolazepam, the benzodiazepine tranquilizer in Telazol, has been suspected of causing the prolonged recovery after intramuscular injection in cats. Flumazenil has been used intravenously (0.1 mg/kg) to antagonize midazolam in cats anesthetized with a combination of ketamine and midazolam. Zolazepam's effect in cats is similarly antagonized by flumazenil, providing an alternative to the apparently slow hepatic metabolism of the benzodiazepines in this species.

Inhalation anaesthetics: Inhalation anesthetics are the best choices for maintenance of anesthesia in patients with severe liver disease. Halothane decreases hepatic blood flow and is metabolized up to 20% by the liver. It is recommended that halothane be avoided, if possible, in patients with liver disease. However, the presence of hepatic disease does not necessarily result in increased hepato-toxicity when a patient is subsequently exposed to an unpredictable hepatotoxin such as halothane. Halothane is metabolized to trichloroacetic acid, which may undergo reductive metabolism to produce hepatotoxins during hypoxic conditions. The trifluoroacetate hapten is subsequently attacked by serum antibodies, causing hepatitis.To ensure adequate blood pressure, flow, and oxygen delivery during anesthesia, precautions should be taken when using halothane. Methoxyflurane decreases hepatic blood flow, and up to 50% of an inhaled dose is metabolized by the liver. In addition, metabolites of methoxyflurane are potential renal toxins. Isoflurane increases hepatic artery blood flow in humans, whereas halothane preserves hepatic arterial flow at 1 MAC but decreases it at 2 MAC. The higher cardiac output associated with isoflurane anesthesia is likely to maintain better hepatic perfusion and oxygen delivery than is halothane. Thus, isoflurane appears to be a good choice for maintenance of anesthesia in patients with hepatic disease.Biotransformation of sevoflurane (3% to 5%) is less than halothane but more than isoflurane or desflurane. Production of the trifluoroacetic acid hapten is extremely low and unlikely to induce an immune response such as the well-documented halothane hepatopathy. Free fluoride-ion production after exposure to sevoflurane is comparable to that from desflurane. Sevoflurane reduces portal vein flow and oxygen delivery more than isoflurane. The effects of desflurane on hepatic blood flow are similar to those of halothane. Desflurane differs from isoflu-rane structurally only by substitution of a fluorine atom for a chlorine atom. The substitution of a fluorine atom for other halogens generally makes a molecule more stable in terms of biotransformation. Indeed, desflurane metabolism to free fluoride ion is less than that of isoflurane. Because of its low metabolism, low blood solubility (enabling rapid induction and recovery from anesthesia), and cardiovascular stability (maintaining hepatic perfusion), desflurane would appear to be a good anesthetic for patients with hepatic disease. Nitrous oxide has been used in patients with hepatic disease in an effort to decrease the amount of volatile anesthetic required for anesthesia.

Muscle relaxants: Non-depolarizing muscle relaxants such as pancuronium and vecuronium are metabolized by the liver. Effects of these relaxants may be prolonged in patients with hepatic disease. Concurrent administration of aminoglycoside antibiotics with non-depolarizing muscle relaxants may also prolong neuromuscular blockade. Atracurium is a non-depolarizing muscle relaxant whose metabolism is independent of hepatic function. Atracurium undergoes plasma degradation via a metabolic pathway termed *Hofmann elimination* that depends primarily on plasma pH and temperature. For patients with hepatic disease requiring neuromuscular blockade, atracurium seems to be a good choice. Succinylcholine is a depolarizing muscle relaxant that is degraded by plasma cholinesterase. Organophosphate compounds have cholinesterase inhibiting activity and may potentiate the action of succinylcholine. Phenothiazine tranquilizers (e.g., acepromazine) may inhibit cholinesterase activity, so succinylcholine should be used cautiously in patients medicated with acepromazine. The use of both acepromazine and succinylcholine should be avoided in patients with hepatic disease. Centrally acting muscle relaxants such as guaifenesin (glyceryl guaiacolate) or mephenesin are metabolized by the liver. Although the margin of safety for use of guaifenesin is wide, side effects following administration of large doses include moderate hypotension, decreased tidal volume, and concentration dependent hemolysis.

Anaesthesia for patients with cardiovascular diseases

The anesthetic management of a patient with cardiovascular dysfunction can be very challenging, because most preanesthetic and anesthetic agents capable of depressing the central nervous system can also produce cardiovascular depression. Patients with cardiovascular dysfunction may be more prone to fluid overload and dysrhythmias Patients with cardiovascular dysfunction may lack sufficient cardiac reserve to compensate for anesthetic-induced depression. Because of the diversity of pathophysiological conditions, no single anesthetic management technique or protocol can be recommended for all animals with cardiovascular dysfunction. Appropriate patient monitoring with arterial blood pressure, central venous pressure, electrocardiogram, end-tidal carbon dioxide, pulse oximetry and other parameters is essential to reduce anesthetic and surgical risk.

Anaesthetic management of patients with impaired cardiac output depends greatly on the underlying pathology, which may require echocardiography for accurate diagnosis. The decreased tolerance of these patients for improper fluid therapy and anesthetic management emphasizes the need for adequate perioperative monitoring and support. These patients should be preoxygenated for 5 to 7 min prior to anesthetic induction. If cardiovascular function is adequate, the choice of anesthetic drugs may not be specific for these patients; however, drugs that may produce tachycardia (anticholinergics and dissociative agents) or large changes in vascular resistance should be used judiciously.

Preanaesthetics: Narcotics are often used as preanesthetic medication because of their minimal effects on the myocardium, and they can be readily antagonized. Indeed, opioids are the mainstay of cardiac anesthesia. Opioids tend to maintain, and may even indirectly improve, myocardial function. They can be used in combination with acepromazine or a benzodiazepine tranquilizer for additional sedation. Use of acepromazine may be contraindicated in some forms of cardiovascular diseases (e.g., hypertrophic cardiomyopathy) but may be beneficial in others (e.g., mitral valve insufficiency) because of the potential for decreased afterload. Opioids can increase vagal afferent activity, which may decrease heart rate. If significant bradycardia occurs, atropine or glycopyrrolate should be given as needed.

If only tranquilization is needed, a low dose of acepromazine (e.g., 0.02 mg/kg) may be administered intramuscularly. Acepromazine decreases peripheral vascular resistance and very often leads to arterial hypotension and reduced preload. Acepromazine can have significant negative inotropic effects. Because of direct myocardial depression, and prominent vasodilatation and hy-potension, the value of inducing sedation/tranquilization must be weighed against the potential adverse effects. Phenothiazines must be used cautiously in most cardiac patients. If acepromazine is administered, patients must be monitored closely and appropriate supportive care used should adverse effects become significant.

The use of alpha 2 adrenergic agonists should be avoided in patients with impaired cardiac output. These drugs can produce significant dysrhythmias, including severe sinus bradycardia and sinoatrial and atrioventricular nodal blocks. Bradycardia, reduced contractility, and increased afterload are disadvantageous effects of these agonists in cardiac patients.

Cardiomyopathy: Since most anesthetic drugs worsen existing myocardial performance, to reduce the risk during the perianesthetic period, treatment of cardiomyopathy is warranted prior to anesthesia. In dogs with dilated cardiomyopathy, anesthesia is best induced with agents that have minimal direct myocardial depressant effects. Etomidate or alphaxalone would be preferable induction agents over either thiopental or propofol. The direct depressant effects of ketarnine on the myocardium may be clinically significant if sympathetic nervous system efferent activity is already maximal or exhausted. The lowest possible concentra tion of an inhalant should be used for maintenance of anesthesia. Anesthesia is less depressing to myocardial performance when an opioid is coadministered, resulting in lower inhalant anesthetic requirements.

Pericardial tamponade and constrictive pericarditis: These are associated with impaired cardiac output caused by reduced stroke volume secondary to reduced end-diastolic ventricular volume. There is limited expansion of the cardiac chambers, resulting in decreased ventricular filling such that heart rate must increase to maintain cardiac output. Pulse pressure is usually decreased, and peripheral pulses may feel abnormal. Myocardial contractility might not be impaired.

Valvular Heart Disease: Although both mitral and tricuspid insufficiencies are often clinically insignificant, ventricular ejection fraction is reduced. Antimuscarinics should be used conservatively, but lower doses of atropine or glycopyrrolate are often used to inhibit anesthetic-associated bradycardia. Alpha 2 adrenergic agonists are contraindicated in patients with valvular insufficiency, because they can affect heart rate and peripheral vascular resistance. Opioids are a principle component of balanced anesthesia for these patients and are generally chosen based on analgesic and sedative requirements. If these patients are stable, anesthesia may be induced with ketamine and diazepam or propofol. Less stable patients may be anesthetized by induction with etomidate or high doses of opioids in combination with a benzodiazepine. To avoid pronounced vasodilatation and hypotension, lower doses of inhalants are used. Use of the inhalants helps to prevent arteriolar vasoconstriction and increased afterload.

Hypertrophic cardiomyopathy: Anaesthesia can be induced by using propofol, etomidate, or a neuroleptanalgesic combination. Mask induction using one of the potent volatile inhalant anesthetics is also an acceptable technique, although the stress of induction may be detrimental to patients with impaired cardiac function. Inhalant anesthetics are most often the maintenance agents for these patients. Isoflurane is one of the preferred inhalants because of preservation of a near-normal cardiac index and minimal dysrhythmic effects in healthy animals, when compared with the effects of halothane. However, in animals with diastolic dysfunction (e.g., HCM) isoflurane may be associated with reduced preload and afterload leading to reduced end-diastolic ventricular volume and increased end-systolic ventricular to aortic pressure gradients when dynamic outflow-tract obstruction is present. Sevoflurane minimally reduces cardiac output and is associated with less vasodilation than is isoflurane at typical anesthetic doses in healthy animals. Animals may maintain a lower heart rate when anesthetized with sevoflurane than with isoflurane, although preanaesthetic drugs may alter the cardiovascular responses to inhalant anesthetics. Based on the lower blood solubility and reduced pungency, sevoflurane may provide for a less stressful inhalant induction compared with either halothane or isoflurane. When a lower heart rate is desired (e.g., for cats with HCM), sevoflurane may be preferred over isoflurane.

Congenital heart disease: When Patent ductus arteriosus (PDA) is ligated, increased blood pressure may cause a reflex slowing of the heart rate which is a normal physiological response. In some instances, antimuscarinic drugs (e.g., atropine or glycopyrrolate) may be needed to counteract the sinus bradycardia. To minimize the potential for bradycardia, an anticholinergic may be administered as a preanaesthetic medication.

Persistent right aortic arch (PRAA) is also usually recognized and corrected early in life. If a patient is normal in other respects, the anesthetic protocol is designed for the pediatric patient undergoing a thoracotomy. It is important to remember that a patient with PRAA may be suffering from aspiration pneumonia.

Anaemia: Anaemic and/or hypoproteinemic patients should have serial PCV and total plasma protein concentration measurements during and after surgery. If an animal is anemic, supplemental oxygen may be beneficial in the preanesthetic period as well as the postoperative period to maintain maximal hemoglobin saturation. A mask, nasal catheter, or oxygen cage can be used to deliver 40% to 100% oxygen to patients. One of the periods of greatest risk for anemic patients is when anesthesia is discontinued and the fraction of inspired oxygen suddenly decreases from near 1.0 to 0.21 (room air) in the presence of anesthetic drug-related respiratory depression. In addition, as a hypothermic patient recovers, shivering will occur, dramatically increasing oxygen demands.

Hypoproteinemia : Many preanesthetic and anesthetic drugs are reversibly bound to plasma proteins, especially albumin. If plasma protein concentration is decreased, a greater fraction of highly protein-bound drug (i.e., protein binding in excess of 80%) is pharmacologically active and therefore will have an increased effect. Plasma protein, primarily albumin, is also required to maintain plasma oncotic pressure. Hypoalbuminemic patients are less tolerant of crystalloid fluid administration and more prone to volume overload and pulmonary edema.

Arrhythymias: Ventricular dysrhythmia is relatively common in dogs and cats during anesthesia, and its incidence is increased with certain anesthetics (e.g., halothane) and diseases (e.g., spleenic neoplasia). Arrhythmia is more common with inappropriate levels of inhalant anaesthetics.Ventricular tachyarrhythmia can be resolved through use, of antiarrhythmics (typically lidocaine or sotalol), by providing deeper anesthesia if the patient is inadequately anesthetized, or by changing to a less arrhythmogenic anesthetic (e.g., changing from halothane to isoflurane). Catecholamine-induced arrhythmia may be more common during illness, after injury, and with other stressors.

Anaesthesia for patients with renal diseases

All anaesthetics are likely to decrease the rate of glomerular filtration. Anesthetics may directly affect RBF, or they may indirectly alter renal function via changes in cardiovascular and/or neuroendocrine activity. Most anesthetics decrease the GFR as a consequence of decreased RBF. Anesthetics that cause catecholamine release (e.g., ketamine, tiletamine, and nitrous oxide) have variable effects on RBF. Inhalation anesthetics tend to decrease RBF and GFR in a dose dependent manner. Light planes of inhalation anesthesia preserve renal autoregulation of blood flow, whereas deep planes are associated with depression of autoregulation and decreases in RBF. Thiobarbiturates increase systemic vascular resistance but decrease renal vascular resistance with no net change in RBF. In contrast, ketamine increases RBF and renal vascular resistance.

Most anesthetics cause less disruption of renal autoregulation of blood flow at lower doses (lighter anesthetic planes). Different responses to anesthetics may occur in controlled studies of RBF compared with clinical use of anesthetics. Renal responses to anesthetics also depend on the preexisting hydration status and quantity of perioperative fluids administered, as well as preexisting renal insufficiency/failure. Due to systemic hypotension or renal vasoconstriction, renal ischemia may occur during anesthesia. Systemic hypotension may be caused by excessive depth of inhalation anesthesia, as all potent halogenated anesthetics cause peripheral vasodilation. Inhalant anesthetics also depress myocardial contractility and cardiac output in a dose-dependent manner. Hypotension may also be induced by phenothiazine or butyrophenone tranquilizers. Phenothiazine and butyrophenone tranquilizers block *alpha* adrenoceptors and dopamine receptors. Alpha adrenergic blockade may induce peripheral vasodilation and hypotension. Dopamine receptor blockade by acepromazine premedication may prevent dopamine-induced increases in RBF during surgery.

Anaesthesia and the stress associated with surgery cause release of aldosterone, vasopressin, renin, and catecholamines. Thus, RBF and GFR (and therefore urine production) are generally decreased with surgery in any patient. For most patients, the effects of inhaled anesthetics on renal function are reversed at the termination of anesthesia. Some patients, however, may not regain the ability to regulate urine production for several days. Some drugs used in the perianaesthetic period have a significant effect on urine production. Alpha 2 adrenergic agonists can dramatically increase urinary output and reduce urinary osmolality. Xylazine is believed to decrease ADH concentration in mares accounting in part for increased urine production. Because adrenergic agonists can induce diuresis, they should not be used in animals that have urethral obstruction. Opioids may cause urine retention when administered systemically or as an epidural injection. Nephrotoxic drugs administered during anesthesia may cause oliguria. Methoxyflurane is the only anesthetic known to cause nephrotoxicity as a consequence of biotransformation to oxalate and free fluoride ion.

Renal insufficiency/failure and renal azotemia in patients with renal insufficiency can alter the response to anesthetics. Patients with renal insufficiency/failure may be acidotic, which will increase the fraction of unbound barbiturate and other injectable drugs in the plasma. Thus, lower doses of highly protein-bound injectable anesthetics may be required in acidotic patients. Hyperkalemia may be present in animals with renal insufficiency/failure, obstructed urethra, or rupture of the urinary bladder Acidosis may be associated with a concurrent increase in serum potassium. Patients in renal failure with hypocalcemia are at even greater risk, because hypocalcemia potentiates the myocardial toxicity of hyperkalemia. Further, administration of succinylcholine will transiently increase serum potassium concentration. Succinylcholine-induced increases in potassium are potentially life threatening in animals with hyperkalemia. In contrast, elevation in serum potassium is not observed after administration of non-depolarizing neuromuscular blocking agents. It should be remembered that patients with hypermagnesemia associated with chronic renal failure may have prolonged recovery from non-depolarizing neuromuscular blocking agents. If hyperkalemia is acute or ECG abnormalities are noted, treatment should be initiated prior to induction of anesthesia. The most rapid treatment for the cardiac effects associated with hyperkalemia is 10% calcium chloride (0.1 mg/kg IV). Calcium will increase the membrane's threshold potential, resulting in increased myocardial conduction and contractility. Because increased serum potassium concentration causes the resting potential to be less negative (partially depolarized), the calcium ion-induced increase in threshold potential temporarily restores the normal gradient between resting and threshold potentials. It should be recognized that administration of calcium will not affect the serum potassium concentration, and its effects will therefore be short-lived. Regimens to decrease the serum potassium concentration by shifting potassium intracellular include bicarbonate administration and combined infusion of glucose and insulin. Because acidemia favors extracellular movement of potassium and worsens hyperkalemia, intermittent positive pressure ventilation may be required to prevent anesthetic drug-induced hypercapnea and respiratory acidosis.

Patients with chronic renal failure may be anemic because of bone marrow suppression, chronic gastrointestinal tract blood loss, reduced red blood cell life span, and decreased erythropoietin production. In response to anemia, the cardiovascular system may become hyperdynamic in an attempt to maintain oxygen delivery. Chronic renal disease may be associated with hypertension and increased cardiac output. Additionally, pulse oximetry can be used to rapidly detect hemoglobin desaturation and alert one to the potential for a decrease in tissue oxygen delivery. In dogs and cats with mild renal insufficiency, a rapid intravenous induction of anesthesia may be accomplished with thiobarbiturates, propofol, etomidate, diazepam-ketamine, or diazepam-opioid combinations. Severely depressed patients can be mask induced with isoflurane or halothane. Anesthesia may be maintained with isoflurane or sevoflurane. The use of medications including non-steroidal anti-inflammatory drugs (NSAIDs) that are potentially nephrotoxic should be avoided.

When renal function is questioned, the urinary bladder can be catheterized and urine production monitored via a closed, sterile urine-collection system. Urine production is an indirect measure of renal perfusion. Empty intravenous fluid bags can be saved for the purpose of collecting urine from catheterized patients. If the urinary tract is not obstructed or the patient is anuric, intravenous fluids should be administered during anesthesia at the rate of 20 ml/kg for the first hour. Lower fluid rates should be used if the patient has mild hypoproteinemia or cardiovascular disease. The choice of intravenous fluid is based on the animal's electrolyte and acid base status. In general, animals with mild to moderate renal insufficiency/failure that are well prepared for surgery or anesthesia are given lactated Ringer's solution. Arterial blood pressure must be measured to detect systemic hypotension and decreased renal perfusion pressure. The central venous pressure (CVP) can be measured via jugular catheter to evaluate the rate of intravenous fluid administration.

Myocardial function may be improved by infusion of dopamine. Low doses of dopamine will also improve RBF either through increased cardiac output, dopaminergic diuretic effects, or both. Improvement in renal perfusion in cats given dopamine is less well documented, but may involve alpha-adrenoceptor stimulation rather than dopamine receptor agonism. Putative renal dopamine receptors (DA I) in cats appear to differ from those identified in kidneys of other species.

Measurements of the GFR and renal tubular function, such as urine specific gravity and blood urea nitrogen (BUN), are not specific for renal disease. Serum creatinine is a more specific indicator of the GFR than BUN because it is influenced by fewer extrarenal variables. It is important to keep in mind that greater than 75% nephron loss is necessary for most patients to become persistently azotemic. Thus, patients with mild renal insufficiency may not have elevated serum creatinine. Persistent proteinuria and/or cellular or granular cylinduria may indicate renal damage prior to the onset of renal azotemia. In addition to BUN, serum creatinine concentrations, and urinalysis, patients with renal insufficiency should be evaluated to determine acid-base balance, electrolyte concentrations (especially potassium), exercise intolerance, hematocrit, hydration, and urine production

Postoperative oliguria: It should be investigated if the animal does not have congestive heart failure or pulmonary edema, a fluid challenge of 5 ml/kg isotonic sodium chloride may be given. If urine production increases, the animal was hypovolemic and fluids should be continued. If not, dopamine may be infused. Dopamine improves renal function when used at low doses by increasing RBF, GFR, urine output, and sodium excretion, and by decreasing renal vascular resistance.

The use of diuretics in the perioperative period is controversial. In a study of human patients, acute renal failure treated with diuretics such as mannitol and furosemide was not resolved. Furosemide is used to promote diuresis in patients with pulmonary edema but should not be used when a patient is known to be hypovolemic. In hypovolemia, furosemide may increase nephrotoxicity of other drugs by increasing their contact time in the renal tubules. Mannitol, an osmotic diuretic, can be given (0.25 to 0.5 g/kg slowly IV) to prevent pulmonary edema or hyponatremia if the kidneys do not respond to fluid administration and the patient becomes volume overloaded.

Urethral obstruction: In small animals with urethral obstruction, fine-needle centesis of the urinary bladder may be performed prior to anesthesia, although bladder injury is a potential concern. Rupture of the urinary bladder during induction of anesthesia in a horse has been described. Perineal urethrostomy may be performed in stallions with urethral blockage by using standing restraint and epidural anesthesia. If general anesthesia is required while the bladder is distended, every attempt should be made to assist the horse into sternal or lateral recumbency during induction.

Anaesthesia may be induced by using injectable or inhalation anesthetics. In many animals, distension of the urinary bladder is associated with increased heart rate. Cats that are chamber induced should not be induced with halothane due to its arrhythmic effects. Chamber induction with isoflurane or sevoflurane is preferred for small animals. Intravenous ketamine with a benzodiazepine has been used in obstructed cats even though active metabolites of the drug are excreted by the kidney. The rationale is that, once the obstruction is relieved, excretion of the anesthetic will proceed normally. However, cats with a long-term urethral obstruction may develop metabolic disturbances and renal insufficiency such that elimination of drugs is slowed even after the obstruction has been removed.

Thus, if dissociative anesthesia is used, low doses of ketamine (1 to 2 mg/kg IV) can be used in combination with diazepam (0.2 mg/kg IV). With low doses, anesthetic action will be reduced after redistribution of the drug into body tissues. More commonly, injectable anesthetic induction in cats with renal disease is performed by administering propofol (2 to 5 mg/kg IV) or etomidate (1.0 mg/kg IV) slowly to effect.

Rupture of the urinary bladder: Animals may become hyperkalemic, hyponatremic, hypochloremic, and acidotic after urinary bladder rupture. Intravenous fluids, such as 0.9% sodium chloride, should be given to aid in correcting electrolyte imbalances. Potassium enters the abdominal cavity from the ruptured bladder and is reabsorbed into the circulation, causing an increased serum potassium concentration. An electrocardiogram should be evaluated prior to induction of anesthesia to determine whether cardiac arrhythmias or evidence of hyperkalemia are present. Anesthesia may be induced by face-mask administration of isoflurane or sevoflurane. Young foals (weighing < 200 kg) may be nasotracheally intubated while awake and then induced rapidly with an inhaled anesthetic. In larger foals, xylazine (1.1 mg/kg IV) or diazepam (0.1 mg/kg IV) in combination with ketamine (2.2 mg/kg IV) can be used for induction. Isoflurane and sevoflurane are preferred over halothane because they possess less myocardial depressant action and potentiation of catecholamine-induced cardiac arrhythmias. Administration of dextrose-containing solutions with or without insulin may be desired to counter hyperkalemia. Positive-pressure ventilation may be used to prevent anesthetic associated hypercapnea and accompanying respiratory acidosis. Appropriate monitoring should be used, including end-tidal carbon dioxide, pulse oximetry, arterial blood-gas analysis, arterial blood pressure, and electrocardiogram assessment.

Bibliography

- Carter, J. E., Motsinger-Reif, A. A., Krug, W. V. and Keene, B. W. (2017). The effect of heart disease on anesthetic complications during routine dental procedures in dogs. *J. Am. Anim. Hosp. Assoc*., **53(4):** 206-213.
- Clifforde, E. L. (2018). Chronic renal disease in dogs and cats: Anaesthesia considerations. *Veterinary Nursing J*., **33(5):**131-137.
- Díaz-Delgado, O. B. and Alderson, B. (2020). Anaesthesia of the patient with chronic kidney disease. *Companion Animal*, **25(11)**: 268-276.
- Dyson, D. H., Maxie, M. G. and Schnurr, D. (1998). Morbidity and mortality associated with anesthetic management in small animal veterinary practice in Ontario. *J. Am. Anim. Hosp. Assoc*., **34(4):** 325-335.
- Gaynor, J. S., Dunlop, C. I., Wagner, A. E., Wertz, E. M., Golden, A. E. and Demme, W. C. (1999). Complications and mortality associated with anesthesia in dogs and cats. *J. Am. Anim. Hosp. Assoc*., **35(1):**13-17.

- Grubb, T.L. (2008). Anesthesia for patients with special concerns. *In:* Small Animal Anesthesia and Analgesia. Carroll, G.L. (ed.).
- Hall, L.W., Clarke, K.W. and Trim, C. M. (2001). Veterinary Anaesthesia. 10th edn. W.B. Saunders: London.
- Jones, J.L. (2002). Perioperative management of patients with liver disease. *In:* Veterinary anesthesia and pain management secrets. Greene, S.A. (ed). Hanley & Belfus, Philadelphia. pp 17-38.
- Khattri, S., Kinjavdekar, P., Amarpal, Aithal, H.P., Pawde, A. M., Kumar, R. and Singh, J. (2013). Dexmedetomidine with butorphanol and propofol for total intravenous anaesthesia in uraemic buffalo calves. *Adv. Anim. Vet. Sci.*, **1(2S):** 15-23.
- Kumar, R., Das, A. K., Aakanksha, Verma, N.K., Aakash, Saxena A. C. and Hoque M. (2025). Effects of anaesthetic protocol on kidney and liver function of female dogs undergoing ovariohysterectomy. *Indian J. Anim. Res*., **59(8):** 1414-1419.
- Kumar, R., Kinjavdekar, P., Amarpal, H.P. Aithal,, A.M. Pawde, A. Kumar, J. Singh and S. Khattri (2013). Haematobiochemical effects of dexmedetomidine with and without butorphanol for propofol and ketamine anaesthesia in uraemic goats. *Indian J. Vet. Surg*., **34(1):** 19-22.
- O'Connor, C. J., Rothenberg, D. M. and Tuman, K. J. (2010). Anesthesia and the hepatobiliary system. *In:* Miller's Anesthesia, 7th edn. Miller, R. D. (ed). Elsevier Churchill Livingstone, Philadelphia. pp 2135-2149.
- Schroeder, C. (2015). Renal disease. *In:* Canine and Feline anesthesia and co-existing disease. Snyder, L. and Johnson, R. (eds). Wiley-Blackwell, Ames, Iowa, pp116-128.
- Sethi, S., Singh, J., Nath, I. and Johnson, D. (2018). Clinico-physiological and haemodynamic evaluation of butorphanol-xylazine/dexmedetomidine-ketamine anaesthesia in canine pyometra patients. *Indian J. Canine Pract.*, **10(2):** 163- 167.
- Thurmon, J.C., Tranquilli, W.J. and Benson, G.J. (2007). Gastrointestinal Disease. *In:* Lumb & Jones' Veterinary Anaesthesia. 3rd edn. Williams & Wilkins, Baltimore. pp 798-803.
- Weil, A.B. (2010). Anaesthesia for patients with renal/hepatic disease. *Topics in Companion Animal Medicine*, **25(2):** 87-91.
- Yankina, I., Ida, K. K., Wesselowski, S. R., Baetge, C. L., Moreno, K. L., Lepiz, M. A. L., Espinoza, M. B. G. and Yankin, I. (2024). Anesthetic management and anesthesia-related complications in dogs with a dilated cardiomyopathy phenotype: a retrospective study of 30 dogs (2010–2024). *J. Am. Vet. Med. Assoc.*, **262(12)**: 1-8.

SUSTAINABLE PEST AND DISEASE MANAGEMENT WITH BIOCONTROL'S IN VEGETABLES

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Introduction

Vegetable crops form an essential part of human nutrition and a major income source for farmers. However, they are extremely vulnerable to insect pests and diseases. Conventional farming has relied heavily on synthetic pesticides to reduce crop losses but such practices have led to issues like pesticide residues on vegetables, environmental contamination, harmful effects on non-target organisms and the development of resistant pest populations. With growing consumer awareness of food safety and environmental concerns, there is an urgent need for sustainable alternatives. Biological control or biocontrol has emerged as a key strategy for managing pests in an eco-friendly manner. Biocontrol uses naturally occurring predators, parasitoids and beneficial microbes to reduce pest populations and suppress plant diseases. It restores ecological balance, enhances soil health and supports long-term productivity, making it ideal for both conventional and organic vegetable farming.

Concept of Biocontrol in Vegetable Production

Biocontrol refers to using living organisms or natural substances to suppress pests and diseases. Unlike pesticides that act broadly and often indiscriminately. Biocontrol works through mechanisms such as predation, parasitism, competition, antibiosis and induced systemic resistance. In vegetable production systems, biocontrol helps reduce pest pressure, prevent disease outbreaks and create a stable agroecosystem where biological interactions naturally regulate pest populations. It can be used in open-field cultivation, protected cultivation (polyhouses, greenhouses) and organic production. They also form a crucial component of Integrated Pest Management (IPM) helping reduce the frequency and quantity of chemical pesticide use.

Major Types of Biocontrol Agents

1. **Predators**

Predators are free-living organisms that feed directly on pest species. They play a significant role in vegetable pest management because many vegetable pests such as aphids, mites, thrips and whiteflies are soft-bodied and highly susceptible to predation.

Ladybird beetles (*Coccinella septempunctata*) consume large numbers of aphids, mealybugs and scale insects and are especially useful in tomato, okra and chili crops.

Green lacewing larvae (*Chrysoperla carnea*) are highly effective biological predators, known for their ability to attack more than 200 pest species, including aphids, jassids and whiteflies. Predatory mites (*Amblyseius swirskii*, *A. cucumeris*) are widely used in greenhouse vegetable production to manage thrips and mites.

Fig 1: Installation of *Tricogramma* egg cards in brinjal

Fig 2: Predator(ladybug beetle)

2. Parasitoids

Parasitoids are insects whose larvae develop inside or on another insect, eventually killing the host. They are extremely effective for managing pests that are difficult to control with chemicals, such as borers and leaf miners.

Egg parasitoids like *Trichogramma chilonis* and *T. pretiosum* are used extensively in tomato, brinjal and okra to manage fruit and shoot borers. They parasitize pest eggs, preventing them from hatching and reducing larval damage.

Larval parasitoids such as *Cotesia plutellae* are highly effective against the diamondback moth, a major pest in cabbage and cauliflower. Parasitoids help break the pest life cycle and maintain low levels of infestation when released periodically.

3. Microbial Biocontrol Agents

Bacterial agents: *Bacillus thuringiensis* (Bt) is one of the safest and most widely used biopesticides in vegetable crops. Bt produces toxins that specifically target caterpillars, causing them to stop feeding and die.

Fungal agents: *Beauveria bassiana* infects pests like whiteflies, thrips, jassids and beetles by penetrating their cuticle. *Metarhizium anisopliae* is useful against soil and foliar pests, including termites and beetles.

Viral agents: Nuclear Polyhedrosis Viruses (NPVs) are used to control Helicoverpa and Spodoptera species in tomato, chili and cabbage. These microbial agents are safe for humans, animals and beneficial organisms.

4. Botanical Biopesticides

Plant extracts such as neem (Azadirachta indica), garlic, pongamia, lantana and eucalyptus are highly effective in vegetable pest suppression. Neem products containing **azadirachtin** act as antifeedants, repellents and growth regulators. Disrupting pest life cycles at multiple stages. Garlic and chilli extracts are effective against sucking pests and act as natural repellents. Botanical pesticides are biodegradable, leave no residues and can be prepared at the farm level by small and marginal farmers.

Biocontrol Agents for Managing Vegetable Pests

a) Tomato and Brinjal Pests

Tomato fruit borer (*Helicoverpa armigera*) and brinjal shoot and fruit borer (*Leucinodes orbonalis*) cause substantial yield losses. *Trichogramma* releases at weekly intervals help suppress these pests. Bt sprays at early larval stages provide excellent control. Predators such as lacewings and ladybird beetles reduce aphids, jassids and whiteflies.

b) Cabbage and Cauliflower Pests

The diamondback moth (DBM) has developed resistance to many chemical insecticides. Biocontrols like Bt var. kurstaki and *Cotesia plutellae* offer sustainable alternatives. *Beauveria bassiana* can also be used to manage aphids and whiteflies in cole crops.

c) Chilli and Capsicum Pests

Thrips and mites are common pests in chilli and capsicum. Predatory mites (*Amblyseius swirskii*) and fungal biocontrols like *Beauveria bassiana* are highly effective. Neem oil reduces viral vectors like whiteflies and thrips.

d) Cucurbits and Okra Pests

In cucurbits, fruit flies, aphids and leafminers are major pests. Neem formulations help reduce fruit fly oviposition. In okra, fruit borers can be suppressed using *Trichogramma* cards and Bt sprays.

Biocontrols for Vegetable Diseases

i. Management of Soil-Borne Diseases

Trichoderma species are effective against soil pathogens causing damping-off, wilts and root rots. They colonize the root zone, compete for nutrients, produce antibiotics and degrade pathogen cell walls using enzymes. *Trichoderma* also stimulates plant root growth and improves nutrient uptake.

ii. Management of Foliar Diseases

Pseudomonas fluorescens and *Bacillus subtilis* suppress foliar pathogens causing early blight, powdery mildew, bacterial leaf spot and downy mildew. They also induce plant immune responses, making plants more tolerant to stress.

iii. Indirect Control of Viral Diseases

Biocontrol agents do not kill viruses but help control the insect vectors that spread them. Whiteflies, aphids and thrips major vectors of viral diseases can be managed using neem oil, entomopathogenic fungi and predatory insects.

Integration of Biocontrols in IPM

Biocontrols are most effective when combined with cultural, mechanical and chemical methods. Crop rotation reduces disease inoculum, while intercropping and mulching confuse pests and suppress weed growth. Pheromone traps help monitor pest populations and sticky traps reduce sucking pests. Resistant varieties and proper spacing reduce disease spread. Chemical sprays should be used only when pest populations exceed economic thresholds and should be selective to avoid harming natural enemies.

Advantages

1. Provides eco-friendly pest control without harming the environment.
2. Reduces chemical residue on vegetables and improves food safety.
3. Helps prevent pest resistance through natural, multiple modes of action.
4. Protects beneficial insects and enhances overall farm biodiversity.
5. Lowers long-term production costs by reducing chemical pesticide use.

Conclusion

Biocontrol-based pest and disease management offers a sustainable, eco-friendly and economically feasible approach for vegetable production. Through the combined use of predators, parasitoids, microbial agents and botanical extracts, farmers can effectively reduce pest populations while preserving ecological balance. When integrated with IPM practices, biocontrols ensure long-term productivity, environmental safety and food quality. With technological advancements and increased farmer awareness, biocontrols will become a cornerstone of sustainable vegetable.

References:

- Chandler, D., Bailey, A.S., Tatchell, G.M., Davidson, G., Greaves, J and Grant, W.P. 2011. The development, regulation and use of biopesticides for integrated pest management. *Philosophical Transactions of the Royal Society*. 366(1573): 1987–1998.
- Chandrasekaran, M and Kim, K. 2017. Trichoderma spp. Biocontrol agents for fungal disease management in vegetables. *Frontiers in Microbiology*. 8(1): 1–16.
- Gurr, G.M., Wratten, S.D and Luna, J.M. 2003. Multi-function agricultural biodiversity: pest management and other benefits. *Basic and Applied Ecology*. 4(2): 107–116.
- Isman, M.B. 2006. Botanical insecticides, deterrents and repellents in modern agriculture and an increasingly regulated world. *Annual Review of Entomology*. 51(1): 45–66.
- Jacobsen, B.J., Zidack, N.K and Larson, B.J. 2004. The role of microbial biofungicides in integrated pest management and sustainable agriculture. *Annual Review of Phytopathology*. 42(1): 337–359.
- Van Lenteren, J.C. 2012. The state of commercial augmentative biological control: plenty of natural enemies, little use. *BioControl*. 57(1): 1–20.

ECOSYSTEM BASED ADAPTATION

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Abstract

Ecosystem-Based Adaptation (EbA) represents a nature-based strategy that leverages biodiversity and ecosystem services to reduce the vulnerability of human communities and ecosystems to the adverse effects of climate change. EbA encompasses the sustainable management, conservation, and restoration of ecosystems such as forests, wetlands, grasslands, and coastal habitats to maintain ecological functions that support climate resilience and sustainable development.This approach enhances adaptive capacity while providing co-benefits including improved water and soil quality, disaster risk reduction, and strengthened livelihoods. By integrating ecological stewardship with participatory governance and socio-economic considerations, EbA offers cost-effective and environmentally sustainable solutions that complement traditional "hard" adaptation measures. The evidence suggests that increased policy recognition and implementation of EbA is critical for addressing climate change impacts in both rural and urban settings globally, although further research and monitoring are needed to optimise outcomes and guide policy integration.

Ecosystem-based Adaptation (EbA) is an approach that integrates biodiversity and ecosystem services into a comprehensive climate adaptation strategy to help communities adjust to the adverse impacts of climate change. It focuses on the sustainable management, conservation, and restoration of ecosystems so they can continue to provide services that support adaptation to both current climate variability and future change. By maintaining the health and functioning of natural systems, EbA reduces vulnerability and strengthens resilience to climate and non-climate risks, while also delivering multiple co-benefits to society and the environment such as enhanced food security, water regulation, and livelihood support.

Background on Ecosystem-based Adaptation (EbA)

Ecosystem-based Adaptation (EbA) is a nature-based climate adaptation approach that integrates biodiversity and ecosystem services into comprehensive strategies to help societies adjust to the adverse impacts of climate change. At its core, EbA works with the natural environment by conserving, sustainably managing, and restoring ecosystems such as forests, wetlands, grasslands, and coastal habitats so that they can continue to provide essential services like water regulation, soil protection, and climate resilience. By maintaining healthy ecosystems, EbA reduces the vulnerability of both ecosystems and human communities to climate hazards such as floods, droughts, coastal erosion, and severe weather, while simultaneously delivering multiple ecological, socio-economic, and cultural benefits. EbA is recognized as a cost-effective adaptation option that can be particularly beneficial to rural and resource-dependent populations, as it builds upon local ecological knowledge and can be integrated into broader adaptation and development planning (Convention on Biological Diversity, 2009; IUCN, 2009).

Additionally, EbA supports sustainable development goals by enhancing ecosystem health, strengthening resilience to non-climate risks, and promoting co-benefits such as improved food and water security (FAO, 2025; UNEP, 2025).

An **ecosystem** is a functional unit of nature in which living organisms (biotic components such as plants, animals, and microorganisms) interact with each other and with their physical environment (abiotic components like air, water, soil, sunlight, and climate) in a given area. These interactions form a dynamic and self-regulating system through which energy flows and matter cycles, sustaining ecological structure and function. The concept of an ecosystem encompasses both the biological community and its physical environment, and it emphasises the interdependence of organisms and their surroundings.

Energy Flow in an Ecosystem

Energy flow is a fundamental ecological process that describes the transfer of energy through an ecosystem's trophic levels. Solar radiation is the primary source of energy for most ecosystems. Producers, mainly photosynthetic organisms such as green plants and algae, capture sunlight and convert it into chemical energy through photosynthesis. This energy is stored in organic molecules and then transferred to consumers (herbivores, carnivores) and decomposers as they feed on other organisms. At each trophic level, only a fraction of the energy (roughly 10% according to ecological principles) is passed on to the next level; the remainder is lost as heat through metabolic processes. Because energy is continually dissipated as heat, the flow of energy is **unidirectional and non-cyclic**, distinguishing it from nutrient cycling.

Ecological Cycles (Nutrient Cycling)

In contrast to energy, matter (nutrients) cycles within ecosystems through a series of biogeochemical processes that recycle essential elements. Nutrient cycling refers to the movement and exchange of organic and inorganic matter between living organisms and the physical environment. These biogeochemical cycles include the carbon, nitrogen, phosphorus, oxygen, sulfur, and water cycles, which ensure that essential nutrients are made available repeatedly to organisms. Decomposers (such as fungi and bacteria) play a critical role in breaking down dead organic matter and releasing nutrients back into the soil or water, where they can be taken up again by producers, completing the cycle. Unlike energy, nutrient cycling is circular and continuous, reflecting the conservation of matter within the biosphere.

Principles for Ecosystem-Based Approaches to Adaptation (EbA)

Ecosystem-based Approaches to Adaptation (EbA) are grounded in ecological and social principles that support the integration of biodiversity and ecosystem services into climate adaptation planning and policy. These principles build on international frameworks—including the Cancun Adaptation Framework under the United Nations Framework Convention on Climate Change (UNFCCC)—and aim to enhance resilience, promote coordinated action, and ensure equitable governance (Andrade *et al.*, 2011; UNEP, 2021).

1. **Promoting Resilience of Ecosystems and Societies:** EbA emphasises simultaneously strengthening the resilience of natural systems and the human communities that depend on them. This involves understanding the characteristics of resilient ecosystems and the services they provide, fostering local ownership through collaboration with rural and vulnerable populations, and supporting stewardship practices that enhance both ecosystem management and livelihoods. Through this approach, EbA contributes to reducing vulnerability to climate impacts while sustaining ecosystem functionality.

2. **Promoting Multi-Sectoral and Collaborative Action:** A core principle of EbA is the promotion of multi-sectoral collaboration, ensuring that sectors managing ecosystems interface effectively with those that benefit from ecosystem services. This includes cooperation across institutional and administrative boundaries to prevent conflicting mandates, and establishing multi-stakeholder processes for adaptation policy development. Such coordination is essential to align ecosystem management with broader development and climate objectives.
3. **Operating at Multiple Spatial Scales:** EbA recognises that ecological and social processes operate across varying geographic scales, from local landscapes to wider regions. Effectively addressing vulnerability requires landscape-scale planning and impact assessments that identify cumulative and indirect stressors, while institutions should foster connections across scales since ecosystem boundaries often do not coincide with political or administrative limits. This perspective supports integrated management that reflects real ecosystem functions rather than human jurisdictions.
4. **Integrating Adaptive and Flexible Management:** Adaptive management is a fundamental principle of EbA, enabling flexible responses to evolving ecological and climatic conditions. This includes decentralising decision-making to the most appropriate level to improve effectiveness, equity, and ownership; addressing resource constraints at local levels to prevent degradation of ecosystem processes; and empowering local institutions, communities, and non-governmental actors who possess intimate environmental knowledge. Long-term monitoring and reflective learning processes are critical to this adaptive management approach, as they support iterative improvement and knowledge exchange.

Climate change mitigation:

According to the Intergovernmental Panel on Climate Change (IPCC), mitigation is defined as *"a human intervention to reduce the sources or enhance the sinks of greenhouse gases"* and is considered essential to counter the root causes of climate change, which are predominantly driven by anthropogenic activities such as the combustion of fossil fuels, deforestation, industrial processes, and certain agricultural practices . These activities emit carbon dioxide (CO_2), methane (CH_4), and other GHGs that trap heat in the Earth's atmosphere, disrupting the planetary energy balance and leading to progressive increases in global temperatures.

Mitigation strategies are critical for restricting global temperature rise and lessening the adverse impacts of climate change on ecosystems, biodiversity, human health, economies, and societies. Effective mitigation requires a suite of technological, economic, social, and policy interventions aimed at reducing GHG emissions, increasing energy efficiency, transitioning to renewable energy sources, enhancing carbon sequestration, and promoting sustainable land use practices. For example, the deployment of renewable energy technologies, improvements in energy efficiency, afforestation and reforestation programs, and carbon capture and storage methods are widely discussed mitigation pathways in the scientific literature.

Principles of Ecosystem-Based Approaches to Adaptation (EbA)

Ecosystem-Based Adaptation (EbA) is an approach to climate change adaptation that leverages biodiversity and ecosystem services to reduce societal vulnerability and enhance resilience. A set of core principles, developed by Andrade et al. (2011), provides a foundation for integrating EbA into policy, planning, and project design. These principles are intended to guide decision-makers in adopting ecosystem-centred adaptation strategies that are ecologically sound, socially inclusive, and context-specific.

First, EbA promotes the resilience of both ecosystems and societies, recognising that the capacity of natural systems to withstand disturbance is intrinsically linked to the adaptive capacity of the human communities that depend on them. Actions guided by this principle aim to maintain and restore ecosystem structure and function while supporting local livelihoods. Second, EbA encourages multi-sectoral approaches, facilitating collaboration among sectors responsible for ecosystem management and those that benefit from ecosystem services to ensure coordinated adaptation planning. Third, EbA operates across multiple geographical scales, from local landscapes to national planning frameworks, acknowledging that ecological processes and climate impacts transcend administrative boundaries.

Fourth, the approach emphasises adaptive and flexible management structures that enable learning, innovation, and iterative decision-making. This includes decentralised governance where appropriate, support for local institutions, and sustainable monitoring mechanisms to inform adaptive responses over time. Fifth, EbA aims to minimise trade-offs and maximise co-benefits by aligning adaptation, conservation, and development goals to avoid unintended negative outcomes. Sixth, it is based on the best available science and local knowledge, fostering knowledge generation, exchange, and utilisation throughout the adaptation process.

Seventh, EbA prioritises the use of nature-based solutions that serve people—particularly the most vulnerable—by enhancing ecosystem services that underpin well-being. Finally, EbA is participatory, transparent, and culturally appropriate, actively embracing equity and gender considerations to ensure inclusive engagement, accountability, and socially just outcomes. Taken together, these principles provide a structured framework for planning and implementing EbA interventions that are both effective and equitable in addressing climate change vulnerability.

Approach of Ecosystem-Based Adaptation (EbA)

Ecosystem-Based Adaptation (EbA) is a nature-based adaptation approach that integrates ecosystem management and the sustainable use of biodiversity to help human communities adapt to the adverse effects of climate change. Across the literature, EbA is framed less as a single intervention and more as a multi-faceted, systems-based approach that links ecological processes, social needs, and governance structures within broader adaptation strategies

Chong (2014) emphasises that EbA approaches are grounded in the recognition that resilient ecosystems underpin human well-being and adaptive capacity. EbA thus involves a range of ecosystem management actions — from restoring coastal wetlands to protect against storm surges, to sustainable watershed and rangeland management — which collectively reduce vulnerability to climate hazards while supporting ecosystem functions and services. This perspective sees EbA as an alternative or complement to conventional “hard” adaptation measures such as engineered infrastructure, often offering cost-effective, flexible, and sustainable solutions.

The Naumann et al. (2011/2013) work on EbA highlights that the approach is not only ecological but also governance-oriented and socially inclusive. EbA strategies are designed to foster climate resilience by integrating biodiversity conservation with socio-economic development goals and by emphasising participatory processes in planning and implementation. In particular, their assessment of EbA's potential in Europe underscores the importance of understanding success factors and barriers — including institutional collaboration, policy integration, and cross-sectoral coordination — that affect uptake and effectiveness of EbA measures. The 2013 policy brief co-authored by Naumann et al. further elaborates that social dimensions such as empowerment of local actors, capacity building, and addressing equity in implementation are critical components of effective EbA approaches.

Munang et al. (2013) contribute to the EbA body of thought by positioning EbA within a broader climate adaptation and sustainable development framework. They define EbA as an approach that promotes the sustainable management, conservation, and restoration of ecosystems to provide essential climate adaptation services while simultaneously delivering multiple co-benefits such as improved livelihoods, enhanced food security, and reduced disaster risk. Munang and colleagues also emphasize the "third win" potential of EbA — linking adaptation with conservation and sustainable economic pathways — and argue that EbA should be seen as an integral part of policy and practice rather than an isolated set of projects.

Ecological-Based Climate Change Adaptation Practices

Ecological-based climate change adaptation practices, often implemented under the umbrella of Ecosystem-Based Adaptation (EbA), employ ecosystem services and nature-based solutions to reduce vulnerability to climate hazards while providing co-benefits for biodiversity, livelihoods, and sustainable development (UNEP, 2025). These approaches typically involve conservation, restoration, and sustainable management of ecosystems to enhance resilience to climate impacts such as flooding, drought, and coastal erosion. EbA practices have been adopted across different ecological and socio-economic contexts globally, reflecting the flexibility and applicability of ecosystem approaches in adaptation planning (UNEP, 2025; Conservation International, 2025)

One widely adopted practice is coastal habitat restoration, including the rehabilitation of mangrove forests and wetlands. Mangrove restoration provides natural flood barriers that reduce wave energy and coastal erosion while supporting fisheries and local livelihoods. For example, in the Seychelles, mangrove and wetland forests spanning 29 hectares have been rehabilitated to strengthen coastal resilience against storm surges and sea-level rise. Similarly, broader EbA projects in Nepal and Mauritania include reforestation and restoration of multi-use greenbelts to enhance soil stability and water regulation in drought-prone areas. These interventions improve freshwater availability and food security while reducing vulnerability to extreme climatic events.

Agroecological practices and sustainable land management represent another set of EbA measures. Restoration and sustainable management of rangelands, for instance, increase soil moisture retention and support livelihoods in drought-affected regions such as Botswana's communal grazing areas, where rangeland vegetation is restored to increase resilience to water scarcity and enhance carbon storage. Agroforestry—integrating trees into agricultural landscapes—helps stabilise soils, regulate microclimates, and increase crop resilience to temperature and precipitation variability, contributing to food security and ecosystem health

Integrated water resource and watershed management is also a key adaptation practice. Protecting and restoring watershed ecosystems, including riparian buffers and natural drainage systems, can regulate water flows, reduce flood risk, and sustain water supplies during drought, thereby enhancing adaptive capacity in both rural and urban areas. EbA strategies often incorporate measures such as watershed rehabilitation and riparian reforestation to buffer climate extremes and maintain hydrological functions.

In agricultural and rural contexts, EbA also includes community-based climate-smart practices such as apiculture (beekeeping), vegetable gardening, and other diversified agricultural activities that build resilience through enhanced ecosystem goods and services. These on-farm practices not only support adaptation by stabilising ecosystem productivity under climate stress but also contribute to local food security and income diversification.

Role of Ecosystem-Based Adaptation in Climate Change

A central role of EbA is reducing vulnerability and building resilience of both ecosystems and local communities. Healthy and functioning ecosystems — such as mangroves, forests, wetlands, and watersheds — act as natural barriers that mitigate the impacts of climate hazards including floods, droughts, storm surges, and coastal erosion. For example, mangrove forests absorb wave energy and stabilise shorelines, reducing the exposure of coastal communities to sea level rise and extreme weather events. EbA thus contributes to both ecological stability and human safety by maintaining ecosystem services that would otherwise be disrupted under climate change.

Beyond direct hazard reduction, EbA supports sustainable development and livelihoods by maintaining the provisioning services of ecosystems. These include clean water, food, fibre, genetic resources, and cultural benefits that are critical for food security, agriculture, fishing, and rural economies. Sustaining these services helps communities adapt to changes in climate patterns by ensuring continuity in essential natural resources on which they depend for their well-being.

EbA also contributes to disaster risk reduction, as the protective functions of ecosystems can complement engineered or "hard" infrastructure solutions, often at lower cost and with additional co-benefits. For example, restoring floodplain forests or wetlands not only reduces flood risk by regulating water flows but also enhances water quality and biodiversity conservation. These integrative benefits make EbA a cost-effective and multi-benefit strategy within broader climate adaptation frameworks.

Furthermore, while primarily an adaptation strategy, EbA can support climate change mitigation by reducing greenhouse gas emissions associated with habitat loss and ecosystem degradation, and by enhancing carbon sequestration in forests, peatlands, and other natural systems. This dual role underscores the synergy between adaptation and mitigation objectives when natural systems are maintained or restored.

EbA encourages inclusive and sustainable governance by involving local communities, traditional knowledge, and participatory planning processes in adaptation interventions. This ensures that adaptation strategies are not only ecologically sound but also socially equitable and culturally appropriate — fostering long-term resilience and ownership of climate adaptation actions.

Conclusion

Ecosystem-Based Adaptation plays a crucial role in climate change adaptation by maintaining and enhancing ecosystem services that buffer communities against climate hazards, thereby increasing resilience and reducing vulnerability to climate impacts. By conserving and restoring natural systems—such as mangroves for coastal protection, wetlands for flood regulation, and forests for water security—EbA provides multi-benefit, cost-effective alternatives or complements to engineered infrastructure (*Wikipedia*, 2025; UNEP, 2025). In addition to adaptation outcomes, EbA contributes to sustainable development goals by supporting biodiversity conservation, improving livelihoods, and strengthening ecosystem governance (*SANBI*, 2025; Conservation International, 2025). Despite its demonstrated potential, broader mainstreaming of EbA into national and international climate strategies is essential, as is continued evidence generation and stakeholder engagement to overcome implementation barriers. Therefore, EbA remains a pivotal component of holistic climate adaptation frameworks that promote ecological integrity and human well-being in the face of ongoing climatic changes (*IIED*, 2025).

References

- Andrade Pérez, A., Córdoba Muñoz, R., Dave, R., Girot, P., Herrera Fernández, B., Munroe, R., Oglethorpe, J., Pramova, E., Watson, J., & Vergara, W. (2011). *Draft principles and guidelines for integrating ecosystem-based approaches to adaptation in project and policy design: A discussion document*. Commission on Ecosystem Management, IUCN & CATIE.
- Chong, J. Ecosystem-based approaches to climate change adaptation: progress and challenges. *Int Environ Agreements* **14**, 391–405 (2014).
- Conservation International. (2025). *Ecosystem-based adaptation*.
- Convention on Biological Diversity. (2009). *Connecting biodiversity and climate change mitigation and adaptation: Report of the Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change*. Montreal: Author.
- Convention on Biological Diversity. (2018). *Biodiversity and climate change*.
- Food and Agriculture Organization of the United Nations. (2025). *Ecosystem-based adaptation*.
- International Union for Conservation of Nature. (2009). *Ecosystem-based Adaptation: A natural response to climate change* (Report). Gland, Switzerland: IUCN.
- IPCC. (2014). *Climate Change 2014: Mitigation of Climate Change* (Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change). Cambridge University Press.
- IUCN. (2011). *Principles and guidelines for integrating ecosystem-based approaches to adaptation (EbA)*.
- Munang, R., et al. (2013). *Framing ecosystem-based adaptation to climate change* (conceptual insights and policy framing). Adapted from Munang et al. framework and used to inform climate-EbA interconnections.
- Muthee, K., Duguma, L., Nzyoka, J., & Minang, P. (2021). *Ecosystem-based Adaptation practices in climate-smart farming systems*. Sustainability, 13(3), 1142.
- Naumann, S., Anzaldúa, G., Berry, P., Burch, S., McKenna Davis, M., Frelih-Larsen, A., Gerdes, H., Sanders, M., & others (2011). *Assessment of the potential of ecosystem-based approaches to climate change adaptation and mitigation in Europe* (Final Report to the European Commission). Ecologic Institute & Environmental Change Institute.
- Naumann, S., McKenna Davis, M., et al. (2013). *The social dimension of ecosystem-based adaptation*. UNEP Policy Series – Ecosystem Management.
- United Nations Environment Programme. (2021). *Guidelines for integrating ecosystem-based adaptation into national adaptation planning*.
- United Nations Environment Programme. (2024). *Ecosystem-based Adaptation (EbA) approach.*
- United Nations Environment Programme. (2024). *Ecosystem-based Adaptation South project factsheet*.

QUALITY CONTROL: STANDARDS AND CHROMATOGRAPHIC ANALYSIS OF HERBAL PRODUCTS

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INTRODUCTION

Herbal products are widely used across the globe for health promotion and disease management. The increasing demand for natural remedies has led to rapid expansion of the herbal industry. However, quality, safety, and efficacy remain major concerns due to variability in raw materials, adulteration, and lack of standardization. Quality control is therefore essential to ensure consistency, therapeutic effectiveness, and consumer safety. Chromatographic techniques play a crucial role in the standardization and analysis of herbal products by enabling precise identification and quantification of bioactive constituents.

IMPORTANCE OF QUALITY CONTROL IN HERBAL PRODUCTS

Quality control ensures that herbal products meet defined standards of identity, purity, strength, and safety. Unlike synthetic drugs, herbal formulations are complex mixtures of multiple compounds. Variations in plant species, geographical origin, harvesting time, processing methods, and storage conditions significantly affect phytochemical composition. Proper quality control minimizes batch-to-batch variation and prevents contamination with pesticides, heavy metals, microbes, and adulterants.

REGULATORY STANDARDS AND GUIDELINES

Several international organizations have developed guidelines for herbal product quality control. The World Health Organization (WHO) has issued guidelines on Good Agricultural and Collection Practices (GACP) and Good Manufacturing Practices (GMP). Pharmacopeias such as Indian Pharmacopoeia, United States Pharmacopeia, European Pharmacopoeia, and Chinese Pharmacopoeia provide monographs for medicinal plants and herbal formulations. These standards specify botanical identification, purity tests, and assay methods.

RAW MATERIAL AUTHENTICATION

Botanical authentication is the first step in quality control. Macroscopic and microscopic evaluation helps confirm plant identity. DNA barcoding is increasingly used for species authentication, especially in powdered samples. Voucher specimens and herbarium references ensure traceability and prevent substitution of inferior species.

PHYSICOCHEMICAL PARAMETERS

Physicochemical evaluation includes determination of moisture content, ash values, extractive values, pH, and solubility. These parameters indicate purity and stability of herbal materials. Loss on drying determines moisture level, while total ash and acid-insoluble ash detect inorganic impurities.

PHYTOCHEMICAL SCREENING

Preliminary phytochemical tests detect major groups such as alkaloids, flavonoids, tannins, saponins, and glycosides. Quantitative estimation of marker compounds provides information on therapeutic potency. Standardization uses chemical markers or fingerprint profiles.

CHROMATOGRAPHIC TECHNIQUES IN HERBAL ANALYSIS

Chromatography is a powerful analytical tool for separation and identification of complex mixtures. Common chromatographic techniques include thin layer chromatography (TLC), high performance thin layer chromatography (HPTLC), high performance liquid chromatography (HPLC), gas chromatography (GC), and hyphenated techniques.

Thin Layer Chromatography (TLC)

TLC is a simple and cost-effective technique for preliminary analysis. It provides qualitative information and helps detect adulteration. Rf values and color reactions are used for compound identification.

High Performance Thin Layer Chromatography (HPTLC)

HPTLC offers improved resolution and reproducibility. It generates fingerprint profiles useful for batch comparison. Densitometric scanning enables quantitative analysis of marker compounds.

High Performance Liquid Chromatography (HPLC)

HPLC is widely used for quantification of bioactive constituents. It provides high sensitivity and precision. Reverse-phase HPLC is commonly employed for phenolics, alkaloids, and glycosides.

Gas Chromatography (GC)

GC is used for volatile compounds such as essential oils. Coupling with mass spectrometry (GC-MS) allows structural elucidation. It is essential for quality control of aromatic plant products.

Hyphenated Techniques

LC-MS, GC-MS, and LC-NMR combine separation with detection for accurate identification. These techniques enhance sensitivity and reliability of analysis.

STANDARDIZATION OF HERBAL FORMULATIONS

Standardization involves establishing consistent quality parameters for finished products. Marker-based standardization uses specific active compounds, while fingerprinting assesses overall chemical profile. Stability studies determine shelf life.

CONTAMINANT ANALYSIS

Herbal products may contain pesticide residues, heavy metals, aflatoxins, and microbial contaminants. Chromatographic and spectroscopic methods ensure compliance with safety limits.

VALIDATION OF ANALYTICAL METHODS

Method validation ensures accuracy, precision, specificity, linearity, and robustness of analytical procedures. International guidelines such as ICH provide validation protocols.

CHALLENGES IN QUALITY CONTROL

Complex plant matrices, lack of reference standards, and variability in chemical composition pose challenges. Adulteration with synthetic drugs and mislabeling remain concerns.

FUTURE TRENDS

Advances in metabolomics, chemometrics, and artificial intelligence will improve quality assessment. Portable analytical devices and rapid screening methods are emerging.

CONCLUSION

Quality control and chromatographic analysis are indispensable for ensuring safety and efficacy of herbal products. Adoption of standardized methods and regulatory compliance will enhance global acceptance of herbal medicine.

REFERENCES

1. World Health Organization. (2007). WHO guidelines on good agricultural and collection practices (GACP) for medicinal plants. WHO Press, Geneva.
2. Kunle, O. F., Egharevba, H. O., & Ahmadu, P. O. (2012). Standardization of herbal medicines. International Journal of Biodiversity and Conservation, 4(3), 101–112.
3. Wagner, H., & Bladt, S. (1996). Plant drug analysis: A thin layer chromatography atlas. Springer-Verlag.
4. Sarker, S. D., Latif, Z., & Gray, A. I. (2006). Natural products isolation. Humana Press.
5. Li, S., et al. (2008). Quality control of herbal medicines. Journal of Pharmaceutical and Biomedical Analysis, 47, 471–482.
6. Reich, E., & Schibli, A. (2007). HPTLC for the analysis of medicinal plants. Thieme.
7. International Conference on Harmonisation (ICH). (2005). Validation of analytical procedures.
8. Stahl, E. (1969). Thin layer chromatography. Springer.
9. Chan, K. (2003). Some aspects of toxic contaminants. Chemosphere, 52, 1361–1371.

INNOVATION AND RESEARCH IN PLANT BASED HEALTHCARE SOLUTIONS

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INTRODUCTION

Plant based healthcare solutions have been an integral part of human civilization for centuries. Traditional medicinal systems such as Ayurveda, Traditional Chinese Medicine, Unani and folk medicine have relied extensively on plants for disease management and health promotion. In recent decades, growing concerns over drug resistance, side effects of synthetic medicines, and rising healthcare costs have revived interest in plant derived therapeutics. Scientific research and technological innovations have transformed traditional knowledge into evidence-based healthcare solutions.

Today, plant based healthcare integrates ethnobotanical wisdom with modern disciplines such as biotechnology, pharmacology, genomics and metabolomics. This multidisciplinary approach has accelerated discovery of novel bioactive compounds, improved standardization, and enhanced therapeutic efficacy. This article discusses recent innovations and research trends in plant based healthcare solutions.

HISTORICAL EVOLUTION OF PLANT BASED MEDICINE

The earliest records of medicinal plants date back to ancient Egyptian papyri, Chinese herbals and Indian Ayurvedic texts. Plants such as neem, turmeric, garlic and ginger were used to treat infections, inflammation and digestive disorders. Indigenous communities developed extensive plant knowledge through observation and experimentation.

The 19th and 20th centuries marked the isolation of active compounds such as morphine, quinine and salicylic acid from plants, laying the foundation of modern pharmacology. These discoveries validated traditional uses and demonstrated the potential of plants as drug sources.

PHYTOCHEMISTRY AND BIOACTIVE COMPOUNDS

Medicinal plants synthesize diverse secondary metabolites including alkaloids, flavonoids, terpenoids, glycosides, phenolics and saponins. These phytochemicals exhibit antimicrobial, anticancer, anti-inflammatory, antidiabetic and antioxidant properties.

Advances in chromatographic and spectroscopic techniques such as HPLC, GC-MS and NMR have enabled precise identification and quantification of bioactive molecules. Metabolomic profiling helps in understanding plant chemical diversity and therapeutic potential.

BIOTECHNOLOGICAL INNOVATIONS

Plant biotechnology plays a significant role in enhancing production of medicinal compounds. Tissue culture techniques such as micropropagation, callus culture and hairy root culture facilitate rapid multiplication and metabolite production.

Genetic engineering enables overexpression of biosynthetic pathway genes to increase yield of valuable compounds. CRISPR technology offers targeted gene editing for trait improvement. Synthetic biology is emerging as a tool to produce plant metabolites in microbial systems.

NANOTECHNOLOGY IN PLANT BASED MEDICINE

Nanotechnology has revolutionized drug delivery systems. Plant extracts and phytochemicals are incorporated into nanoparticles to improve bioavailability, stability and targeted delivery. Green synthesis of nanoparticles using plant extracts is eco-friendly and cost-effective.

Nano-formulations enhance therapeutic efficacy and reduce toxicity. Curcumin, resveratrol and quercetin nano-carriers have shown promising results in cancer and inflammatory disorders.

EVIDENCE BASED HERBAL MEDICINE

Clinical research has strengthened the credibility of herbal drugs. Randomized controlled trials evaluate safety and efficacy of standardized extracts. Herbal formulations are now integrated into complementary and integrative medicine practices.

Pharmaco-vigilance and toxicological studies ensure consumer safety. Regulatory frameworks have been developed for quality control and labeling of herbal products.

ROLE OF ARTIFICIAL INTELLIGENCE AND BIOINFORMATICS

Artificial intelligence aids in drug discovery by predicting bioactivity and molecular interactions. Bioinformatics tools analyze genomic and proteomic data to identify therapeutic targets. Virtual screening accelerates identification of lead compounds from plant databases.

Machine learning models help optimize extraction methods and predict pharmacokinetics of phytochemicals.

PLANT BASED VACCINES AND IMMUNOTHERAPY

Transgenic plants are used to produce vaccines and antibodies. Edible vaccines in banana, potato and rice are under development. Plant expression systems offer safe and scalable production of biopharmaceuticals.

Research on plant derived immunomodulators supports treatment of autoimmune and infectious diseases.

SUSTAINABILITY AND CONSERVATION STRATEGIES

Overharvesting threatens medicinal plant biodiversity. Conservation strategies include in situ and ex situ preservation, community cultivation and organic farming. Good Agricultural and Collection Practices ensure sustainable supply.

Climate smart agriculture and agroforestry promote resilience of medicinal plant systems.

COMMERCIALIZATION AND ENTREPRENEURSHIP

Plant based healthcare has created new business opportunities. Herbal startups develop innovative products such as nutraceuticals, cosmeceuticals and functional foods. Value chain development improves farmer income and rural employment.

Intellectual property rights protect traditional knowledge and novel formulations.

CHALLENGES AND LIMITATIONS

Standardization, adulteration and quality variation remain major challenges. Limited clinical evidence and regulatory barriers affect global acceptance. Lack of awareness and skilled manpower restricts research growth.

Interdisciplinary collaboration is needed to overcome these barriers.

FUTURE PROSPECTS

Future research will focus on omics technologies, personalized herbal medicine and digital health integration. Plant metabolite libraries and open-access databases will enhance discovery.

Public-private partnerships will accelerate innovation and commercialization.

CONCLUSION

Innovation and research have transformed plant based healthcare from traditional practice to modern therapeutics. Integration of biotechnology, nanotechnology and digital tools has enhanced drug discovery and delivery. With sustainable cultivation and scientific validation, plant based solutions will play a vital role in future healthcare systems.

REFERENCES

1. Dewick, P. M. (2009). Medicinal natural products: A biosynthetic approach (3rd ed.). John Wiley & Sons, UK.
2. Fabricant, D. S., & Farnsworth, N. R. (2001). The value of plants used in traditional medicine. Environmental Health Perspectives, 109, 69–75.
3. Edris, A. E. (2007). Pharmaceutical and therapeutic potentials of essential oils. Phytotherapy Research, 21, 308–323.
4. Sangwan, N. S., Farooqi, A. H. A., Shabih, F., & Sangwan, R. S. (2001). Regulation of essential oil production. Plant Growth Regulation, 34, 3–21.
5. World Health Organization. (2013). WHO traditional medicine strategy 2014–2023. WHO Press, Geneva.
6. Khan, M. S. A., Ahmad, I., & Chattopadhyay, D. (2014). New look to phytomedicine. Academic Press.
7. Verpoorte, R., et al. (2010). Metabolomics and medicinal plants. Planta Medica, 76, 253–261.
8. Patra, J. K., et al. (2018). Nano based drug delivery systems. Journal of Nanobiotechnology, 16, 71.
9. Fischer, R., et al. (2012). Plant based vaccines. Plant Biotechnology Journal, 10, 414–425.

PHYTOREMEDIATION AS A SUSTAINABLE STRATEGY FOR ENVIRONMENTAL REMEDIATION

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Abstract

Environmental contamination by heavy metals, organic pollutants, and industrial wastes poses a serious threat to ecosystems and human health. As heavy metals are non-biodegradable, they persist in the environment, have potential to enter the food chain through crop plants, and eventually may accumulate in the human body through biomagnification. Conventional remediation techniques are often expensive, disruptive, and environmentally invasive. Phytoremediation, a plant-based remediation technology, has emerged as a sustainable, cost-effective, and environmentally friendly alternative for the cleanup of contaminated soils, sediments, and water bodies. This chapter provides a comprehensive overview of phytoremediation, including its fundamental principles, major methods, advantages, and limitations. The chapter highlights the role of plants and associated microorganisms in contaminant removal, stabilization, and degradation, and discusses the potential of phytoremediation as a green technology for sustainable environmental management.

1. Introduction

Rapid industrialization, urbanization, mining, agricultural intensification, and improper waste disposal have led to widespread environmental pollution. Contaminants such as heavy metals (e.g., cadmium, lead, mercury), petroleum hydrocarbons, pesticides, and chlorinated solvents persist in the environment and accumulate in food chains, posing severe ecological and health risks. Traditional remediation techniques, including excavation, soil washing, thermal treatment, and chemical stabilization, are often costly and may further degrade soil structure and biodiversity. In response to these challenges, phytoremediation has gained increasing attention as an eco-friendly and aesthetically pleasing remediation strategy.

Phytoremediation utilizes green plants, sometimes in association with rhizospheric microorganisms, to remove, transform, immobilize, or detoxify pollutants from contaminated environments. The technology is particularly suitable for large-scale, low-to-moderate contamination sites and aligns well with the principles of sustainable development.

2. Phytoremediation Methods

Phytoremediation encompasses several distinct mechanisms, each suited to specific contaminants and environmental conditions.

2.1 Phytoextraction

Phytoextraction involves the uptake of contaminants, primarily heavy metals, from soil or water and their accumulation in plant biomass. (Ali *et al*. 2013)

The process of phytoextraction of heavy metals involves several sequential steps:

(i) mobilization of heavy metals in the rhizosphere
(ii) uptake of heavy metals by plant roots
(iii) translocation of heavy metal ions from roots to the aerial parts of the plant and
(iv) sequestration and compartmentalization of heavy metal ions within plant tissues

Appropriate selection of plant species is critical for effective phytoextraction. Plants used for phytoextraction should possess the following characteristics:

(i) high tolerance to the toxic effects of heavy metals
(ii) strong extraction capacity with the ability to accumulate high concentrations of heavy metals in aboveground tissues
(iii) rapid growth and high biomass production
(iv) abundant shoot development and an extensive root system
(v) good adaptation to prevailing environmental conditions, including the ability to grow in poor or contaminated soils, as well as ease of cultivation and harvesting; and
(vi) high resistance to pathogens and pests and low palatability to herbivores, thereby reducing the risk of heavy metals entering the food chain."

High biomass–producing crops, such as *Helianthus annuus*, *Cannabis sativa*, *Nicotiana tabacum*, and *Zea mays*, have been reported to effectively remove heavy metals from contaminated soil through phytoextraction (Kayser *et al.* 2000, Tlustos *et al.* 2006, Vangronsveld *et al.* 2009, Herzig *et al.* 2014). Grasses can also be used for phytoextraction because of their short life cycle, high growth rate, greater biomass production, and high tolerance to abiotic stresses (Malik *et al.* 2010). For example, *Trifolium alexandrinum* has been identified as a suitable candidate for the phytoextraction of Cd, Pb, Cu, and Zn due to its rapid growth, resistance to pollution stress, high biomass yield, and the ability to undergo multiple harvests within a single growth period (Ali *et al.* 2012). Woody species can produce a very high amount of biomass compared to herbs and shrubs, which facilitates the accumulation of high levels of heavy metals in their aboveground biomass. They also possess deep root systems that can effectively reduce soil erosion and prevent the dispersal of contaminated soil into the surrounding environment (Suman *et al.* 2018).

2.2 Phytostabilization

In phytostabilization, plants reduce the mobility and bioavailability of contaminants in soil by immobilizing them through root adsorption, precipitation, or complexation. This method is particularly effective for mine tailings and metal-contaminated soils, preventing erosion, leaching, and further spread of pollutants.

The selection of appropriate plant species is crucial for effective phytostabilization. To achieve highly efficient phytostabilization, plants must be tolerant of heavy metal stress. Since plant roots play a pivotal role in immobilizing heavy metals, stabilizing soil structure, and preventing soil erosion, selected species should possess dense and well-developed root systems. Additionally, plants should be capable of rapid growth and high biomass production to ensure timely establishment of vegetation cover at contaminated sites. The plant cover should also be easy to maintain under field conditions.

To enhance the efficiency of phytostabilization, organic or inorganic amendments may be incorporated into contaminated soils. These amendments can modify metal speciation and reduce the solubility and bioavailability of heavy metals by altering soil pH and redox conditions (Burges et al., 2018). In addition, the application of soil amendments can increase organic matter content and the availability of essential nutrients, while improving the physicochemical and biological properties of the soil. These improvements facilitate plant establishment, enhance root development, and increase the soil's water-holding capacity.

2.3 Phytodegradation (Phytotransformation)

Phytodegradation refers to the breakdown of organic contaminants within plant tissues through metabolic processes. Enzymes such as dehalogenases and peroxidases play a key role in degrading compounds like pesticides, explosives, and petroleum hydrocarbons into less toxic forms.

➢ Mechanisms of Phytodegradation

Phytodegradation occurs through a combination of plant uptake, enzymatic transformation, and compartmentalization of contaminants.

➢ Uptake and Translocation

Organic contaminants present in soil or water are absorbed by plant roots and translocated to various tissues, including stems and leaves. The uptake efficiency depends on the chemical properties of contaminants, such as molecular size, solubility, and lipophilicity.

➢ Enzymatic Transformation

Once inside the plant, contaminants are metabolized through enzymatic reactions similar to detoxification processes in animals. Key enzymes involved include:

- Dehalogenases, which remove halogen atoms from chlorinated compounds
- Peroxidases and laccases, which oxidize phenolic and aromatic compounds
- Nitroreductases, which reduce nitro groups in explosives such as TNT
- P450 monooxygenases, which play a central role in oxidative metabolism

These enzymatic reactions convert complex organic pollutants into intermediate metabolites and eventually into less toxic end products.

➢ Compartmentalization and Conjugation

Following transformation, degradation products may be conjugated with sugars, amino acids, or organic acids and sequestered in plant vacuoles or cell walls. This process reduces toxicity and prevents interference with plant metabolic functions.

➢ Contaminants Targeted by Phytodegradation

Phytodegradation has been successfully applied to a variety of organic contaminants, including:

- Petroleum hydrocarbons
- Polycyclic aromatic hydrocar (PAHs)
- Pesticides and herbicides
- Chlorinated solvents (e.g., trichloroethylene)
- Explosives (e.g., TNT, RDX)
- Industrial dyes and phenolic compounds

2.4 Rhizodegradation (Phytostimulation)

Rhizodegradation, also known as phytostimulation, is a phytoremediation process in which the degradation of organic contaminants in soil is enhanced by the activity of microorganisms in the rhizosphere the narrow zone of soil surrounding plant roots. Unlike phytoextraction, which involves direct uptake of contaminants by plants, rhizodegradation relies on plant–microbe interactions to stimulate microbial populations capable of breaking down pollutants.

Plant roots release a wide range of organic compounds, known as root exudates, including sugars, amino acids, organic acids, enzymes, and secondary metabolites. These exudates serve as carbon and energy sources for soil microorganisms, thereby increasing microbial biomass and activity in the rhizosphere. Enhanced microbial activity promotes the biodegradation of organic contaminants such as petroleum hydrocarbons, polycyclic aromatic hydrocar (PAHs), pesticides, herbicides, and chlorinated compounds.

The effectiveness of rhizodegradation depends on several factors, including plant species, root architecture, soil properties, contaminant type and concentration, and environmental conditions such as moisture, temperature, and nutrient availability. Plants with extensive root systems and high exudation rates are particularly effective in stimulating microbial degradation processes.

Rhizodegradation offers several advantages, including minimal disturbance to soil structure, cost-effectiveness, and improved soil fertility and biological activity. However, its application is generally limited to organic pollutants, as heavy metals cannot be degraded but may instead be immobilized. Additionally, the process can be relatively slow and may result in incomplete degradation or the formation of intermediate metabolites.

Overall, rhizodegradation is a sustainable and environmentally friendly remediation strategy that harnesses natural plant–microbe interactions to enhance the breakdown of organic contaminants in polluted soils. When combined with other phytoremediation approaches, rhizodegradation can significantly improve the effectiveness of site remediation efforts.

2.5 Phytovolatilization

Phytovolatilization is a phytoremediation strategy in which plants absorb contaminants from soil, transform them into less toxic volatile forms, and subsequently release them into the atmosphere through transpiration via leaves or foliage. This approach can be applied for the detoxification of organic pollutants and certain heavy metals such as Se, Hg, and As (Mahar *et al.* 2016).

Elemental mercury (Hg) is liquid at room temperature and can be easily volatilized. Owing to its high reactivity, Hg exists mainly as the divalent cation Hg^{2+} after its release into the environment (Marques et al., 2009). After being taken up through either roots or leaf absorption, methylmercury is converted into ionic Hg, which is subsequently transformed into the relatively less toxic elemental form and volatilized into the atmosphere (Bizily *et al.* 2000).

The main advantage of phytovolatilization compared with other phytoremediation strategies is that heavy metal (metalloid) contaminants are removed from the site and dispersed as gaseous compounds without the need for plant harvesting and biomass disposal. However, as a remediation strategy, phytovolatilization does not completely eliminate pollutants from the environment. Instead, it transfers contaminants from soil to the atmosphere, where the volatilized toxic compounds may contribute to ambient air pollution. Moreover, they may be redeposited onto the soil through precipitation (Vangronsveld *et al.* 2009). Therefore, a thorough risk assessment is required before its application under field conditions.

2.6 Constructed Wetlands

Constructed wetlands utilize aquatic plants to remediate contaminated water through a combination of phytoremediation, sedimentation, and microbial processes. They are widely used for wastewater treatment and removal of nutrients, heavy metals, and organic pollutants.

Advantages of phytoremediation (Hossein et al. 2016)**:**

- **Environmentally friendly**

Phytoremediation uses natural plant processes, making it an eco-friendly and sustainable approach that does not introduce harmful chemicals into the environment.

- **Cost-effective**

It is significantly less expensive than conventional remediation techniques such as excavation or thermal treatment, as it requires minimal equipment, energy, and labor.

- **Minimal soil disturbance**

The method preserves soil structure and fertility, unlike mechanical methods that can damage soil and disrupt ecosystems.

- **Suitable for large areas**

Phytoremediation is ideal for treating large contaminated sites with low to moderate pollution levels where other remediation methods may be impractical.

- **Improves soil quality**

Plants enhance soil organic matter, microbial activity, and nutrient availability, contributing to long-term soil restoration.

- **Prevents soil erosion**

Vegetation cover stabilizes soil, reduces wind and water erosion, and limits the spread of contaminants.

- **Aesthetic and publicly acceptable**

Green vegetation improves landscape appearance and is generally well accepted by local communities.

- **Versatile application**

Different phytoremediation mechanisms (phytoextraction, phytostabilization, phytodegradation, rhizodegradation, phytovolatilization) allow treatment of various contaminants.

Disadvantages of Phytoremediation (Hossein *et al.* 2016)

- **Slow remediation process**

Phytoremediation requires long time periods, often several growing seasons, to achieve effective contaminant removal.

- **Limited root depth**

Contaminant removal is restricted to the plant root zone, making it ineffective for deep soil contamination.

- **Plant toxicity and stress**

High concentrations of contaminants can inhibit plant growth or cause plant death, reducing remediation efficiency.

- **Climate and seasonal dependence**

Plant growth and remediation efficiency are influenced by climate, temperature, and seasonal variations.

- **Risk of food chain contamination**

Accumulated contaminants in plant tissues may enter the food chain if plants are consumed by animals or humans.

- **Biomass disposal issues**

Harvested plant biomass containing contaminants must be carefully managed and disposed of or treated safely.

- **Limited contaminant range**

Phytoremediation is ineffective for some pollutants, especially those that are not bioavailable or cannot be absorbed or degraded by plants.

- **Incomplete remediation**

In some cases, phytoremediation may immobilize or transform contaminants rather than completely remove them from the environment.

- **Risk of food chain contamination**

Accumulated contaminants in plant tissues may enter the food chain if plants are consumed by animals or humans.

- **Biomass disposal issues**

Harvested plant biomass containing contaminants must be carefully managed and disposed of or treated safely.

- **Limited contaminant range**

Phytoremediation is ineffective for some pollutants, especially those that are not bioavailable or cannot be absorbed or degraded by plants.

References:

- Ali, H, Khan, E. and Sajad, M. A. 2013. Phytoremediation of heavy metals-concepts and applications. Chemosphere 91, 869–881. doi: 10.1016/j. chemosphere.2013.01.075

- Ali, H, Naseer, M, and Sajad, M. A. 2012. Phytoremediation of heavy metals by Trifolium alexandrinum. Int. J. Environ. Sci. 2, 1459–1469. doi: 10.6088/ijes. 002020300031
- Bizily, S. P, Rugh, C. L. and Meagher, R. B. 2000. Phytodetoxification of hazardous organomercurials by genetically engineered plants. Nat. Biotechnol. 18, 213–217. doi: 10.1038/72678
- Burges, A, Alkorta, I, Epelde, L. and Garbisu, C. 2018. From phytoremediation of soil contaminants to phytomanagement of ecosystem services in metal contaminated sites. Int. J. Phytoremediat. 20, 384–397. doi: 10.1080/15226514. 2017.1365340
- Herzig, R, Nehnevajova, E, Pfistner, C, Schwitzguebel, J. P. Ricci, A. and Keller, C. 2014. Feasibility of labile Zn phytoextraction using enhanced tobacco and sunflower: results of five-and one-year field-scale experiments in Switzerland. Int. J. Phytoremediat. 16, 735–754. doi: 10.1080/15226514.2013.856846
- Hossein, F, Nastaein, Q, Zaman, Ramlah, M, Tajuddin. and Hamed. F. 2016. Advantages and disadvantages of phytoremediation: A concise review. Int J Env Tech Sci. 2: 69–75.
- Kayser, A, Wenger, K, Keller, A, Attinger, W, Felix, H. and Gupta, S. 2000. Enhancement of phytoextraction of Zn, Cd, and Cu from calcareous soil: the use of NTA and sulfur amendments. Environ. Sci. Technol. 34, 1778–1783. doi: 10.1021/es990697s
- Malik, R. N, Husain, S. Z. and Nazir, I. 2010. Heavy metal contamination and accumulation in soil and wild plant species from industrial area of Islamabad, Pakistan. Pak. J. Bot. 42, 291–301.
- Marques, A. P, Rangel, A. O, and Castro, P. M. 2009. Remediation of heavy metal contaminated soils: phytoremediation as a potentially promising clean-up technology. Crit. Rev. Env. Sci. Technol. 39, 622–654. doi: 10.1080/ 10643380701798272
- Suman, J, Uhlik, O, Viktorova, J. and Macek, T. 2018. Phytoextraction of heavy metals: a promising tool for clean-up of polluted environment. Front Plant Sci. 9:1476. doi: 10.3389/fpls.2018.01476
- Tlustos, P, Szakova, J, Hrubı, J, Hartman, I, Najmanova, J. and Nedilnik, J. 2006. Removal of as, Cd, Pb, and Zn from contaminated soil by high biomass producing plants. Plant Soil Environ. 52, 413–423. doi: 10.17221/3460-pse
- Vangronsveld, J, Herzig, R, Weyens, N, Boulet, J, Adriaensen, K. and Ruttens, A. 2009. Phytoremediation of contaminated soils and groundwater: lessons from the field. Environ. Sci. Pollut. R 16, 765–794. doi: 10.1007/s11356-009 0213-6
- Yan, A, Wang, Y, Tan, S. N, Mohd, Yusof, M. L, Ghosh, S. and Chen, Z. (2020). Phytoremediation: A Promising Approach for Revegetation of Heavy Metal-Polluted Land. Front. Plant Sci. 11:359. doi: 10.3389/fpls.2020.00359

EXOTIC VEGETABLES: CONSUMPTION PATTERNS AND DEMAND DYNAMICS IN TELANGANA

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Abstract

Rapid urbanization, globalization of diets and expansion of organized food services have significantly altered vegetable consumption patterns in India. Exotic vegetables have emerged as a high-value niche segment with strong growth potential, particularly in metropolitan regions. Telangana, with Hyderabad as a major urban consumption hub, represents one of the fastest-growing markets for exotic vegetables in South India. Considering the importance of the subject, the Department of Horticulture, Telangana and Centre for Good Governance (CGG), Hyderabad have conducted a detailed field study on "*Consumption and Demand of Exotic Vegetables in Telangana*". This chapter provides a the gist of the study report - scientific assessment of consumption trends, demand dynamics, supply chain structure, market segmentation, price behaviour, production gaps and future expansion potential of exotic vegetables in Telangana. Using primary survey-based data and secondary sources, the study estimates present consumption levels, identifies key demand drivers and evaluates production feasibility under protected cultivation systems. The findings highlight heavy dependence on inter-state supply, limited local production and high market volatility, emphasizing the need for integrated production planning, protected cultivation expansion and institutional market linkages. The chapter contributes empirical evidence to support policy formulation and research-based planning for sustainable exotic vegetable development.

1. Introduction

The global vegetable market has witnessed a paradigm shift in consumer preferences, with increasing demand for high-value, nutritionally diverse and aesthetically appealing vegetables. Exotic vegetables such as broccoli, coloured capsicum, iceberg lettuce, zucchini and cherry tomato have become integral components of modern urban diets due to rising health awareness and culinary diversification. In India, this transformation is strongly linked to urbanization, growth of the hospitality sector, international exposure and expansion of organized retail.

Telangana represents a unique case study for exotic vegetable demand assessment due to Hyderabad's role as a global IT and service sector hub. The city hosts a large migrant workforce, international corporate offices, star hotels, airline catering services and premium retail outlets, all of which create sustained demand for exotic produce. However, the state's domestic production capacity remains limited, resulting in heavy dependence on supplies from other states such as Tamil Nadu, Maharashtra and Karnataka.

Understanding consumption patterns and demand dynamics is essential for developing targeted production strategies, reducing transportation costs, minimizing post-harvest losses and enhancing farmer participation in high-value horticulture. This chapter therefore adopts a scientific research framework to analyze market structure, consumer demand behaviour and production planning for exotic vegetables in Telangana.

2. Conceptual Framework: Exotic Vegetables in High-Value Horticulture

Exotic vegetables fall under the category of high-value horticultural crops characterized by high market price, specialized production requirements and premium consumer segments. Their production is primarily dependent on protected cultivation systems such as polyhouses and net houses, which enable controlled microclimatic conditions and year-round production.

From an economic perspective, exotic vegetables exhibit higher input costs but also significantly higher gross returns compared to traditional vegetables. From a supply chain perspective, these crops require cold chain integration, rapid transportation and quality-based grading systems. Therefore, demand assessment and production planning must be integrated with infrastructure development and institutional support mechanisms.

3. Objectives and Scope of the Study

Considering the importance of the subject, the Department of Horticulture, Telangana and Centre for Good Governance (CGG), Hyderabad have conducted a detailed field study on "*Consumption and Demand of Exotic Vegetables in Telangana"*.

The specific objectives of the study include:

- Quantification of exotic vegetable consumption in Telangana
- Analysis of demand drivers and consumer behaviour
- Assessment of market segmentation and supply chain structure
- Evaluation of price trends and market volatility
- Estimation of local production gaps
- Development of scientific production planning strategies

The scope of the study covered major exotic vegetables including coloured capsicum, broccoli, iceberg lettuce, zucchini, red cabbage, cherry tomato, baby corn, asparagus, celery, parsley, avocado and button mushroom.

4. Methodology

4.1 Research Design

A descriptive and analytical research design was adopted to capture both quantitative demand estimates and qualitative market insights. Due to the absence of official consumption statistics for exotic vegetables, stakeholder-based primary data collection was prioritized.

4.2 Primary Data Collection

Primary surveys were conducted among wholesalers, supermarket chains, hotels, restaurants, airline catering agencies and polyhouse growers in Hyderabad metropolitan region. Structured questionnaires were used to collect information on daily consumption volumes, procurement sources, price patterns and seasonal demand fluctuations.

4.3 Secondary Data Sources

Secondary information was sourced from the Department of Horticulture, Telangana, Centre for Good Governance reports, SKLTSHU research publications and national horticulture databases.

4.4 Analytical Techniques

Data analysis involved estimation of average daily consumption, annual demand projections, percentage share analysis, growth trend extrapolation and qualitative supply chain mapping.

5. Consumption Pattern of Exotic Vegetables in Telangana

5.1 Aggregate Consumption Levels

Hyderabad city accounts for nearly the entire exotic vegetable demand in Telangana. Average daily consumption is estimated at 11.01 MT, translating into an annual demand of approximately 4,018.98 MT. Category-I exotic vegetables such as coloured capsicum, broccoli and iceberg lettuce constitute the major share of consumption, followed by specialty vegetables and mushrooms.

Table 1: Consumption of Exotic Vegetables in Telangana (Hyderabad)

Crop	Daily Consumption (MT)	Annual Consumption (MT)
Coloured Capsicum	1.74	636.14
Iceberg Lettuce	1.15	420.62
Broccoli	1.34	490.14
Zucchini	0.49	179.02
Red Cabbage	0.36	131.23
Baby Corn	2.16	790.19
Button Mushroom	1.46	531.56
Avocado	1.51	550.68
Others	0.80	289.40
Total	11.01	4018.98

5.2 Share in Total Vegetable Basket

Despite rapid growth, exotic vegetables constitute only about 0.42 percent of total vegetable consumption in Hyderabad. Per capita exotic vegetable consumption remains extremely low compared to conventional vegetables, indicating substantial untapped market potential.

6. Consumer Behaviour and Demand Drivers

Urban consumers increasingly prefer exotic vegetables due to health awareness, dietary diversification and convenience-oriented food consumption patterns. Higher-income households, working professionals and expatriate populations constitute major consumer segments.

The HoReCa sector plays a dominant role in demand generation by incorporating exotic vegetables into continental, Mediterranean and fusion cuisines. Organized retail outlets further stimulate demand by improving product visibility, quality assurance and availability.

7. Market Segmentation and Demand Structure

Table 2: Segment-wise Daily Consumption of Exotic Vegetables

Segment	Consumption (MT/day)	Share (%)
HoReCa Sector	5.92	54.0
Supermarkets	3.46	31.6
E-Commerce Platforms	1.58	14.4
Total	11.01	100

The HoReCa sector dominates demand due to bulk procurement and daily operational requirements, while retail and e-commerce segments contribute steadily growing volumes.

8. Supply Chain Structure and Inter-State Dependency

The supply chain of exotic vegetables in Telangana is heavily dependent on long-distance transportation. Ooty region in Tamil Nadu contributes around 41 percent of supply, followed by

Maharashtra (35.26 percent) and Karnataka (20.45 percent). Local Telangana production accounts for only 2.55 percent of total supply.

Table 3: Source-wise Supply Share

Source Region	Share (%)
Ooty (Tamil Nadu)	41.00
Maharashtra	35.26
Karnataka	20.45
Telangana	2.55

Such dependency increases transportation costs, post-harvest losses and price volatility.

9. Price Behaviour and Market Volatility

Exotic vegetable markets exhibit significant price fluctuations due to supply seasonality and logistics dependency. Wholesale to retail price spread averages around 2.5 times, indicating high marketing margins and value addition through retail channels.

Table 4: Price Characteristics

Parameter	Value
Average Wholesale Price (Rs/kg)	123
Average Retail Price (Rs/kg)	347
Average Price Spread	2.5 Times
Wholesaler Profit Margin	36.9%

10. Local Production Status and Constraints

Local production of exotic vegetables in Telangana remains limited and seasonal, primarily confined to peri-urban polyhouse clusters. Major constraints include high initial investment cost, technical knowledge gaps, limited market linkages and risk perception among farmers.

11. Demand Projection and Growth Outlook

Demand projections indicate annual growth rate of approximately 15 percent for Category-I exotic vegetables. Total demand is expected to reach nearly 4,888.83 MT by 2025–26, driven by urban population growth and hospitality sector expansion.

12. Scientific Production Planning Strategy

12.1 Crop Prioritization

Based on market demand and climatic suitability, priority crops include coloured capsicum, broccoli, iceberg lettuce, zucchini, baby corn and cherry tomato.

12.2 Protected Cultivation Expansion

Polyhouse and net house cultivation should be expanded in peri-urban clusters to ensure consistent supply, quality control and year-round production.

12.3 Cluster-Based Production Model

Formation of exotic vegetable clusters supported by common pack houses and cold chain facilities will enhance economies of scale and market integration.

13. Policy Implications

- Strengthening protected cultivation subsidy programs
- Promotion of farmer producer organizations
- Integration of market intelligence systems
- Establishment of dedicated exotic vegetable wholesale hubs

14. Conclusion

The exotic vegetable market in Telangana is characterized by rapid demand growth, limited local production and heavy inter-state dependency. Scientific production planning, protected cultivation adoption and institutional market support are critical for developing a sustainable exotic vegetable ecosystem. Telangana has strong potential to emerge as a regional hub for exotic vegetable production by leveraging peri-urban agriculture and technology-driven horticulture systems.

References

1. Department of Horticulture, Government of Telangana (2020). Study on Consumption and Demand of Exotic Vegetables in Telangana.
2. Centre for Good Governance (2020). Exotic Vegetable Market Assessment Report.
3. SKLTSHU (2020). Protected Cultivation Research Reports.
4. Ministry of Agriculture and Farmers Welfare (2020). Horticulture Statistics at a Glance.
5. FAO (2019). High Value Crop Production Systems.

APICAL ROOTED CUTTINGS (ARC) TECHNOLOGY OF POTATO: SCOPE AND CHALLENGES IN TELANGANA

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1. Introduction

Potato (*Solanum tuberosum* L.) occupies a prominent position among global food crops due to its high productivity, superior dry matter accumulation, short duration, and rich nutritional profile. Among non-cereal crops, potato is recognized for producing the highest edible biomass per unit area and time, which makes it an efficient crop for addressing food and nutritional security challenges. The Food and Agriculture Organization has acknowledged potato as a strategic crop capable of contributing significantly to future food security and poverty alleviation. In India, potato cultivation has gradually expanded from traditional hill ecosystems to plains and subtropical agro-climatic zones owing to improved irrigation infrastructure, varietal adaptation, and rising market demand. Telangana, with its expanding irrigated area, improving horticultural infrastructure, and proximity to urban consumption centers, holds substantial potential for potato cultivation. However, the sustainable expansion of potato production in the state is constrained primarily by the limited availability of quality seed tubers at affordable prices. This challenge necessitates the adoption of alternative seed multiplication technologies that can ensure timely availability of disease-free planting material while reducing production costs. Apical Rooted Cuttings technology, developed by the International Potato Center, has emerged as a promising solution for decentralized seed production in non-traditional potato-growing regions and offers considerable scope for Telangana under appropriate institutional and policy support.

2. Potato Production Scenario in Telangana

Potato cultivation in Telangana is currently confined to limited pockets, with a total cultivated area of approximately 3,376 acres and an annual production of about 32,747 metric tonnes (2023-24). The average productivity recorded in the state is around 9.7 tonnes per acre, which remains below the national potential levels. Sangareddy district accounts for the largest share of potato area, followed by Vikarabad and Siddipet districts. The cropping season for potato in Telangana is predominantly during Yasangi or Rabi season, with sowing carried out during October and November and harvesting completed by January and February. The majority of potato growers in the state belong to the small and marginal farmer category, cultivating less than four acres per holding. Despite limited cultivation area, Telangana's annual potato consumption demand is estimated at nearly 2.04 lakh metric tonnes, highlighting a wide production-consumption gap and a strong opportunity for local production expansion. The dependence on external markets for potato supply not only increases consumer prices but also reduces income opportunities for local farmers. Bridging this demand-supply gap requires a reliable and cost-effective seed production system capable of supporting area expansion and productivity improvement.

3. Seed Potato Supply Constraints

The availability of quality planting material remains the most critical constraint limiting potato cultivation in Telangana. The state requires approximately 3,200 metric tonnes of seed tubers annually for its existing area, assuming an average seed rate of eight quintals per acre. At present, most seed tubers are procured from northern states such as Himachal Pradesh and Uttar Pradesh or sourced through licensed suppliers affiliated with the Central Potato Research Institute.

This long-distance procurement involves transportation over distances exceeding 1,500 to 2,000 kilometers, which increases logistics costs, delays delivery schedules, and often results in physiological deterioration of seed tubers. Furthermore, seed tubers alone constitute nearly 40 to 50 percent of the total cost of potato production, making cultivation economically risky for small farmers. High seed prices have compelled some farmers to use undersized or discarded tubers as planting material, leading to poor crop establishment, higher disease incidence, and reduced yields. In addition, cold storage dependency for seed preservation between harvest and next planting season adds significant financial burden, as tubers harvested in February or March must be stored for seven to eight months before the next sowing window. These constraints collectively restrict farmer participation in potato cultivation and highlight the urgent need for alternative seed production approaches suitable to Telangana's agro-ecological conditions.

4. Limitations of Conventional Seed Production Systems

The traditional potato seed production system in India primarily relies on the Seed Plot Technique, which is practiced extensively in northern hill regions and selected plains with low aphid populations. This method requires strict vector control to minimize viral disease transmission. Telangana's climatic conditions, characterized by higher temperatures and favorable environments for aphid proliferation, make the adoption of this technique highly challenging. Frequent vector infestations increase the risk of degeneration of seed quality and reduce the effectiveness of conventional seed multiplication. Although advanced technologies such as True Potato Seed, diploid hybrid TPS, and tissue culture-based multiplication have been introduced, their large-scale adoption has been limited due to technical complexity, market acceptance issues, and limited institutional infrastructure. In this context, Apical Rooted Cuttings technology offers a practical balance between technical feasibility, economic viability, and scalability for decentralized seed production.

Alternative technologies include:

- True Potato Seed (TPS)
- Tissue culture-based seed multiplication
- Diploid hybrid TPS
- Apical Rooted Cuttings (ARC)

Among these, ARC technology is emerging as the most farmer-friendly, decentralized, and scalable solution for seed multiplication in tropical and subtropical environments.

5. Concept and Operational Framework of ARC Technology

Apical Rooted Cuttings technology is a tissue culture-based rapid multiplication system originally developed by the International Potato Center in Peru and subsequently refined for commercial deployment in several Asian countries, including Vietnam and India. The technology is based on the principle of vegetative multiplication using apical shoot segments derived from disease-free tissue culture plants.

he ARC production system involves the following steps:

1. **Tissue Culture Initiation**
   Disease-free microplants are produced using nodal explants under controlled laboratory conditions.

2. **Mother Bed Establishment**
   Microplants are planted in insect-proof net houses or nurseries using cocopeat-based raised beds.

3. **Apical Cutting Collection**
   Apical shoots (2–3 cm with two leaves) are harvested every 12–15 days.

4. **Rooting Phase**
   Cuttings are rooted in protrays filled with cocopeat.

5. **ARC Transplanting**
   Rooted cuttings (15–20 days old) are transplanted into protected structures or open fields for seed tuber production.

6. **Seed Multiplication Cycle**
   - G0: Tubers produced from ARC plants
   - G1: G0 tubers planted to produce next generation
   - G2: Distributed to farmers as certified seed material

Within **45 days**, one microplant can generate **8 or more rooted cuttings**, enabling exponential multiplication.

The process begins with the production of virus-free microplants in tissue culture laboratories under controlled conditions. These microplants are then transferred to protected nursery environments to establish mother beds. From these mother plants, apical shoot tips measuring approximately two to three centimeters and containing two functional leaves are periodically harvested at intervals of twelve to fifteen days. These cuttings are either replanted in mother beds for further multiplication or transferred to protrays filled with cocopeat for rooting. Within a period of about forty-five days, a single microplant can generate up to eight or more rooted cuttings, allowing exponential multiplication of planting material. The rooted cuttings are transplanted into insect-proof net houses or open fields to produce the first generation of seed tubers, commonly referred to as G0 tubers. These tubers are subsequently multiplied in open fields to generate G1 and G2 generations, which are supplied to farmers as certified seed material. This multistage multiplication system significantly reduces the time required to produce large volumes of quality seed compared to conventional tuber-based multiplication methods.

6. Infrastructure Requirements and Production Economics

The successful implementation of ARC technology requires moderate but specialized infrastructure, including a tissue culture laboratory, insect-proof nursery structures, protray systems, rooting media such as cocopeat, and access to cold storage facilities for seed tuber preservation. Establishment of a basic ARC production unit involving one tissue culture laboratory and two protected net houses requires an investment of approximately thirty-five lakh rupees. However, once established, the operational costs are relatively low due to rapid multiplication rates and reduced dependency on large-scale cold storage systems. Experiences from Karnataka indicate that a nursery area of about one thousand square meters can produce between six to ten lakh ARC plants annually, which is sufficient to plant approximately thirty to forty acres of potato crop. The sale of ARC planting material at affordable rates has enabled nursery entrepreneurs to generate substantial annual income while simultaneously improving seed availability for farmers. This decentralized nursery-based production model also creates employment opportunities in rural areas and promotes local entrepreneurship.

7. Field Experiences from CIP and Karnataka Model

The most prominent implementation of ARC technology in India has been carried out through collaboration between CIP and the University of Horticultural Sciences, Bagalkot, under the Rashtriya

Krishi Vikas Yojana program. Hassan district in Karnataka has emerged as a leading example, where ARC-based seed multiplication has been adopted by both institutional nurseries and private entrepreneurs. Field observations indicate that ARC plants exhibit uniform crop establishment, rapid canopy development, and improved plant vigor compared to conventional seed tubers. Farmers have reported satisfactory yields and improved seed health status. However, initial generations of ARC-derived tubers have shown variability in tuber size and shape, with a higher proportion of undersized tubers in G0 generation. These limitations are gradually being addressed through varietal selection, improved agronomic practices, and optimized nutrient management. The Karnataka experience demonstrates that ARC technology is technically feasible, economically viable, and socially acceptable when supported by institutional training and extension services.

8. Scope of ARC Technology in Telangana

The introduction of ARC technology in Telangana presents significant opportunities for strengthening the potato value chain and achieving seed self-reliance. By establishing localized seed production hubs, Telangana can reduce its dependence on northern seed markets, minimize transportation losses, and ensure timely availability of planting material. ARC technology aligns well with the state's horticulture development strategies focused on crop diversification, income enhancement, and promotion of high-value crops. Existing infrastructure such as Centres of Excellence, government nurseries, agricultural universities, and private tissue culture laboratories can be leveraged to initiate ARC multiplication programs. Study tours conducted by Telangana officials and progressive farmers to CIP and UHS facilities have demonstrated strong institutional interest and readiness for technology adoption. Pilot-scale introduction of ARC technology can act as a catalyst for scaling up potato cultivation in suitable agro-climatic zones of the state.

9. Agro-Climatic and Technical Challenges

Despite its potential, the adoption of ARC technology in Telangana faces several challenges. High temperatures during the Kharif season may adversely affect tuberization, requiring location-specific evaluation and seasonal optimization. The prevalence of aphids and other insect vectors increases the risk of viral transmission, necessitating strict nursery hygiene and protected cultivation practices. Cold storage dependency remains a constraint for seed tuber preservation between cropping seasons, and storage costs can significantly influence economic viability. In addition, the availability of skilled manpower for tissue culture operations, nursery management, and quality control remains limited. Further research is required to identify ARC-suitable potato varieties that perform well under Telangana's climatic conditions and to standardize agronomic practices for maximizing tuber yield and quality.

10. Institutional and Policy Framework

The successful integration of ARC technology into Telangana's horticulture sector requires strong institutional coordination and policy support. Collaboration with CIP for technology transfer, training programs, and standard operating procedure development is essential. Government support in the form of subsidies for infrastructure development, nursery establishment, and farmer training can accelerate adoption. Integration of ARC technology under national schemes such as the Mission for Integrated Development of Horticulture and Rashtriya Krishi Vikas Yojana can provide financial backing and programmatic support. Public-private partnerships involving tissue culture labs, farmer producer organizations, and private nurseries can create sustainable production and distribution networks. Establishment of seed certification and quality monitoring frameworks will further enhance farmer confidence and market acceptance of ARC-derived planting material.

11. Conclusion

Apical Rooted Cuttings technology represents a transformative innovation capable of addressing the chronic seed shortage challenges faced by potato growers in Telangana. By enabling rapid multiplication of disease-free planting material, reducing dependency on long-distance seed procurement, and promoting decentralized nursery systems, ARC technology can significantly enhance potato production sustainability. With phased implementation, institutional capacity building, adaptive research, and targeted policy support, Telangana has the potential to emerge as a self-reliant potato seed production hub in South India. The strategic integration of ARC technology into the state's horticulture development framework can contribute to improved farmer incomes, employment generation, and long-term food security.

References

1. International Potato Center (CIP). ARC Technology Manuals and Project Reports. Lima, Peru.
2. Department of Horticulture, Telangana (2023). Note on Potato Cultivation Scenario and Scope for ARC Technology.
3. Study Tour Report on ARC Technology, CIP–UHS Bengaluru & Hassan (2023). Government of Telangana.
4. Central Potato Research Institute (CPRI). Seed Production Standards and Certification Guidelines.
5. Ministry of Agriculture & Farmers Welfare (MIDH). Operational Guidelines on Vegetable Seed Production.
6. FAO (2019). Potato Contribution to Global Food Security.

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