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ARTICLE ID: 01

Butea monosperma (Palash): A Potential Agroforestry System for Sustainable Livelihoods in the Bundelkhand Region

Introduction

Butea monosperma (Lam.) Taub., commonly known as Palash or the "Flame of the Forest," is an ecologically and socio-economically significant tree species widely distributed across the dry tropical regions of India. In the semi-arid Bundelkhand region, characterized by erratic rainfall, recurrent droughts, and degraded soils, *B. monosperma* holds special importance due to its remarkable adaptability and multiple livelihood-supporting attributes. The region's fragile agro-ecological conditions demand resilient land-use strategies that can simultaneously enhance productivity, restore ecological balance, and strengthen rural income sources. In this context, agroforestry systems based on hardy native species like Palash offer a promising pathway toward sustainable development.

Butea monosperma is highly valued for its diverse uses—its leaves, flowers, bark, seeds, and resin support a range of traditional household, medicinal, and small-scale industrial applications. The species contributes significantly to Non-Timber Forest Produce (NTFP) livelihoods, offering income opportunities through products such as leaf plates, natural dyes, fodder, lac cultivation, and traditional herbal formulations. Its ecological benefits are equally noteworthy: Palash improves soil fertility through nitrogen-fixing associations, enhances organic matter, provides shade and microclimate amelioration, and plays a key role in rehabilitating degraded lands. Its deep root system and drought tolerance make it well suited for the marginal farmlands of Bundelkhand, where conventional crops often fail under climatic stress.

Integrating *Butea monosperma* into agroforestry models can strengthen climate resilience, diversify farm income, and create a more stable and sustainable livelihood base for rural communities. The species' compatibility with agricultural crops, low management requirements, and suitability for boundary plantations, silvipastoral systems, and NTFP-oriented models further enhance its agroforestry potential. Moreover, as a native species deeply embedded in local culture and traditions, Palash aligns well with community-led resource management and conservation efforts.

Given the urgent need for sustainable land-use alternatives in Bundelkhand, *Butea monosperma*-based agroforestry systems present a viable and impactful solution. Exploring its ecological attributes, livelihood benefits, and suitability under regional conditions can contribute meaningfully to developing integrated, climate-smart agroforestry strategies tailored to the needs of this drought-prone landscape.

B. monosperma

Ecological Importance

Being a multipurpose tree, it serves ecological and environmental purposes by providing uses (for fodder, fuel, non-timber forest products (NTFPs), etc.), carbon sequestration, nutrient cycling support, and religious significance. Thus, it is a favorable choice for cultivation in forestry-pastoral systems, border plantations, and wastelands.

• It can grow in highly saline environments, poorly drained marshy soils, and waterlogged black cotton soils and can also adapt to low water supplies.

• Additionally, the rapid decomposition of the nutrient-rich leaves of the Palash tree improves soil fertility by increasing soil organic carbon.

• Natural dyes and colors are produced from Palash leaves and flowers, which are environmentally friendly and have no harmful effects compared to other synthetic dyes.

• Dona-Pattal, or bowls used for religious or other purposes (approx. 1400-1500 per tree), makes it an eco-friendly technology to avoid the use of plastic to control plastic pollution and helps in mitigating the effects of climate change and reducing carbon footprint.

Uses of Butea Monosperma

Leaves: Used for preparing plates and bowls for religious ceremonies and rituals and for cattle feed.

Flowers: The flowers are used as herbal tea, natural color, dye, and vegetable.

Seeds: Used medicinally to treat urinary complications.

Root: The root fibers are used to make ropes and are also used to treat elephantiasis and night blindness.

Bark: Palash gum is obtained from the bark of the Palash tree, which can be used to treat dysentery and other ailments.

Gum or Resin: A reddish secretion is obtained from the bark, which hardens into a gum called 'Butea gum' or 'Bengal Kino.' It can be used as a dye and tannin.

Wood: Palash wood is dry and light and is used as fuel and as "surcha," a wooden spoon made for Havan (fire sacrifice), and also for house construction in rural areas.

Medicine: The flowers are useful in treating liver disorders, and the seeds act as an anthelmintic. The astringent gum exuded from the cut stem has medicinal properties as a powerful astringent and is used in cases of diarrhea.

Products made from Butea monosperma

Leaf cups/plates: Butea leaves are traditionally used by rural communities to make plates and cups, locally called 'dona pattal,' especially in the Bundelkhand region, and provide livelihoods for the villagers.

Healthy and eco-friendly plates and cups made from Butea monosperma leaves

These are a great alternative to polyethylene or plastic-based plates or cups, as they are healthy and safe and completely biodegradable, thus avoiding any environmental pollution. Nowadays, health-conscious people are beginning to prefer such plant- or leaf-based plates or cups for popular dishes.

Traditional method of gum tapping and collection: Tribal people collect Butea gum during the months of November to February. Trees with a circumference of 25-30 cm are identified for gum tapping. The upper bark, or dead bark, is removed, and incisions of 0.5 to 2.5 cm in length and 1.0 cm in depth are made using a specially designed billhook in an upward direction. These incisions are typically spaced 5 cm apart and made only at a reachable height for easy access. These gum-seeping incisions are observed regularly for a week, and the hard, brittle, ruby-colored beads of gum are collected using a sharp knife.

Butea-gum exudate from natural harvested and processed gum

Palash Dye and Holi Colors: Butea monosperma flowers are a rich source of natural dyes ranging from bright yellow to deep orange-red, often used to color silk, cotton fabrics, leather goods, and foods. This dye is also used for forehead markings in Hinduism. Its bark is used for tanning, which laborers use. It can also be used as a colorant in soft drinks and other fast-food items. Butea flowers have been used to prepare traditional Holi colors for centuries. Even today, natural dyes are produced from these flowers in the region around Brij (Mathura, Uttar Pradesh), which are much healthier and safer than modern-day synthetic and toxic Holi colors.

Lac Cultivation: Lac is an important textile product and has been cultivated in India for centuries as a national heritage. Butea-based lac production is highly popular in India, especially in states like Jharkhand, Chhattisgarh, and Madhya Pradesh. It also provides a very good source of revenue for the tribal people and rural poor of these states. There is a very close relationship between B. monosperma and lac cultivation. A single tree often yields 1.5 to 2.5 kg of lac, which can generate an income of over 1200 to 1500 rupees for the grower. However, incentives should be provided to promote B. monosperma-based lac cultivation, which will not only increase lac production but also ensure the creation of rural livelihoods and conservation of the B. monosperma species.

Butea Honey: Its bright orange flowers are a great source of honey production. The abundant availability of Palash flowers during the months of March and April provides a wonderful opportunity for beekeeping and the honey business. Furthermore, the flowers and nectar have good nutritional and medicinal properties, improving the quality of the honey. Furthermore, during these months, the lack of flower availability makes it difficult for bees to collect nectar. This not only conserves the bee population but also provides a unique opportunity for honey production businesses. Several self-help groups (SHGs) involving rural women in Jharkhand are producing Teshu-Madhu (Palash Honey) from Butea plantations or forests and exporting it to various states and even abroad.

Lac cultivation using Butea monosperma as the host plant (Source: Jaiswal and Singh, 2015)

Nursery Growing Techniques

Seed Propagation

• Collect fresh, healthy, and well-dried seeds from the plant, which have high viability.

• Palash seeds generally do not require pre-treatment.

• Prepare a soil mixture of soil, organic manure, and coco peat in a 25:25:50 ratio and fill it in polybags to support a strong root system.

• Sow seeds in polybags containing the soil mixture to a depth of about 1-2 inches in May and water to moisten the soil.

• Seeds take one to three weeks to germinate, depending on the variety, under good heat and light conditions.

• Typically, 3–6-month-old seedlings are ready for transplanting into the field at a height of 3 feet.

• During August, seedlings can be transplanted into open field conditions.

• Stump planting can also be done from one-year-old seedlings in the primary bed.

• Bonemeal, neem cake, mustard cake, and single superphosphate can also be added to the soil to support the growth of potted plants.

Direct Sowing Technique

• Collect fresh, healthy, and dry seeds

• Seeds can be sown directly in the field in well-drained loamy soil with a pH of 6-7.

• Alternatively, seedlings can be grown in nursery conditions at a spacing of 10 x 10 cm.

• Once the seedlings have developed, they can be transplanted to a suitable and marked site at the beginning of the monsoon.

• Palash (Butea monosperma) is a source of sustainable livelihood in Bundelkhand

Transplanting the Seedlings

• Seedlings are ready for transplanting when they are about 3 feet tall.

• Select a suitable location and dig a hole approximately 30 x 45 cm in size using a posthole digger before the rains.

• Fill the hole with healthy loamy soil mixed with a generous amount of compost or farmyard manure.

• With the onset of rains, remove the polybag and take out the seedlings. Place them gently in the center of the pit without damaging the seedling.

• Fill the pit with the remaining soil, press it down firmly, and irrigate to saturate the soil.

• Water the plant regularly and avoid overwatering as waterlogging can cause root rot.

• Need-based management practices such as fertilization and weeding can be followed for better establishment and maintenance of the plant.

Maintenance of Young Plants

• Plants require six hours of direct sunlight a day.

• These plants require fertile, organic, well-drained soil to thrive.

• Water the plants once a week, making sure to avoid water getting on the leaves.

• Water the plant from the base up and avoid

overwatering.
• Water more frequently in the summer and less frequently in the winter months.
• Apply nitrogen fertilizer to the soil before sowing the seeds. Water the soil immediately after applying fertilizer.
• It is advisable to plant the plant at night and keep it in a shady place for at least two to three days before moving it to its original location.
• In case of disease infestation, spray citrus oil, eucalyptus oil, or neem oil as a preventative measure.

Economic Importance

• Palash provides raw material for gum, dyes, lac, beekeeping, plates and fodder.
• On average, Palash trees yield approximately 2000-3000 rupees per tree per year.
• Gum (300 grams per tree), lac (1.5-2.5 kilograms per tree), and honey production contribute to income generation.

Conclusion

Palash is a potential multipurpose species for a sustainable source of income and livelihood for rural and tribal people. It can also be planted for wasteland reclamation, in agroforestry systems, or as a plantation on farm boundaries for additional profits.

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THE ROLE OF SOIL AND WATER IN FOOD PRODUCTION

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Abstract

Soil and water are fundamental to global food production, serving as the foundation for agricultural sustainability. Soil provides essential nutrients, structural support and a habitat for plants, while water is vital for photosynthesis, nutrient transportation and maintaining soil moisture. However, challenges such as soil degradation, water scarcity, pollution and climate change pose significant threats to food security. Healthy soil supports plant growth by offering a balanced structure, nutrient cycling and microbial activity. Soil fertility is maintained through organic matter decomposition, microbial interactions and sustainable practices like crop rotation and conservation tillage. Additionally, soil's ability to retain water determines agricultural productivity, with loamy soil offering the optimal balance of moisture retention and drainage. Water is a critical resource in agriculture, facilitating irrigation, livestock hydration and crop resilience. Various irrigation techniques, including drip, sprinkler and flood irrigation, impact water efficiency. Water quality also influences soil health and crop productivity, as contamination from agricultural runoff and pollutants can degrade ecosystems. Soil and water management challenges, including erosion, overuse and contamination, require sustainable solutions. Conservation agriculture, efficient irrigation methods, organic farming, agroforestry and soil moisture conservation techniques play a vital role in preserving these resources. Ensuring the long-term viability of soil and water resources is critical for food security. Through sustainable practices, technological advancements and policy support, the agricultural sector can mitigate environmental impacts while meeting the growing demand for food production.

Keywords: Agriculture, Food, Irrigation, Soil, Water

Introduction

Soil and water are the fundamental pillars of agriculture and food production, supporting the growth of crops and livestock that sustain human populations. As the global population increases, the demand for food also rises, making the preservation and efficient use of these natural resources critical. Soil provides essential nutrients and a habitat for plants, while water is necessary for photosynthesis, nutrient transportation and maintaining soil moisture. However, issues such as soil degradation, water scarcity and climate change threaten food security worldwide.

The Importance of Soil in Food Production

1. Soil as a Medium for Plant Growth

Soil is the foundation for plant life, providing structural support, nutrients and water retention capabilities. Different types of soil are loamy, sandy and clay affect the ability of plants to absorb essential nutrients. Healthy soil contains organic matter, microorganisms and minerals that contribute to plant growth.

2. Nutrient Cycling and Fertility

Soil is rich in essential nutrients such as nitrogen (N), phosphorus (P) and potassium (K) which are vital for plant growth. The presence of organic matter and microorganisms facilitates nutrient cycling, breaking down dead plant material into forms that plants can absorb. Soil fertility management through crop rotation, composting and fertilization ensures sustained agricultural productivity.

3. Soil Structure and Water Retention

The structure of soil determines its ability to retain water and allow root penetration. Loamy soil, with a balance of sand, silt and clay is considered the best for agriculture as it retains moisture while allowing adequate drainage. Poor soil structure, often caused by over-farming and erosion, leads to reduced agricultural productivity.

4. Soil Microbial Activity

Healthy soil hosts diverse microbial communities that play crucial roles in decomposing organic matter, fixing nitrogen and improving soil structure. Mycorrhizal fungi form symbiotic relationships with plant roots, aiding nutrient uptake. Bacteria, such as rhizobia, contribute to nitrogen fixation, enhancing soil fertility.

The Role of Water in Food Production

1. Water as a Primary Resource in Agriculture

Water is essential for crop irrigation, livestock hydration and food processing. It facilitates photosynthesis, enabling plants to convert sunlight into energy. Adequate water supply ensures plant resilience against environmental stress and improves crop yield.

2. Irrigation Systems and Efficiency

Irrigation is a crucial component of modern agriculture, allowing for food production in regions with insufficient rainfall. Various irrigation systems include:

- **Drip Irrigation:** Directs water to plant roots, minimizing wastage and improving efficiency.
- **Sprinkler Irrigation:** Simulates natural rainfall but may lead to higher evaporation rates.
- **Flood Irrigation:** Common in traditional farming but results in significant water loss through runoff.

3. The Impact of Water Quality on Agriculture

Water quality affects soil health and crop productivity. Contaminated water containing heavy metals, pesticides or excessive salts can degrade soil fertility and harm plant growth. Sustainable agricultural practices emphasize using clean water sources to ensure food safety and prevent soil degradation.

4. Climate Change and Water Availability

Climate change has led to unpredictable weather patterns, increasing the frequency of droughts and floods. These extreme conditions affect water availability for agriculture, requiring adaptive strategies such as rainwater harvesting and drought-resistant crop varieties.

Challenges in Soil and Water Management

1. Soil Degradation and Erosion

Soil erosion, caused by deforestation, overgrazing and unsustainable farming, reduces soil fertility and agricultural output. Wind and water erosion remove the nutrient-rich topsoil, making it harder for plants to thrive.

2. Water Scarcity and Overuse

Global water demand for agriculture is increasing, with irrigation accounting for 70% of freshwater usage. Over-extraction of groundwater leads to depletion and salinization, reducing water quality and affecting food production.

3. Pollution and Contamination

Agricultural runoff containing pesticides, fertilizers and industrial waste contaminates water bodies, leading to reduced water quality and ecosystem damage. Sustainable farming techniques such as organic farming and controlled fertilizer use help mitigate these issues.

4. Climate Change and Soil Health

Rising temperatures and erratic rainfall patterns contribute to desertification and soil degradation. Soil carbon sequestration and conservation tillage are methods used to counteract these effects and maintain soil fertility.

Sustainable Soil and Water Management Practices

1. Conservation Agriculture: Conservation agriculture promotes minimal soil disturbance, crop rotation and cover cropping to enhance soil health. These practices prevent erosion, improve water retention, and boost crop productivity.

2. Efficient Irrigation Techniques: Adopting water-saving irrigation systems like drip irrigation and rainwater harvesting reduces water wastage and ensures consistent water supply for crops.

3. Organic Farming and Soil Restoration: Organic farming minimizes chemical inputs, enhances soil microbial activity, and promotes biodiversity. Composting and green manure improve soil organic matter and fertility.

4. Agroforestry and Reforestation: Agroforestry integrates trees and crops, reducing soil erosion, improving water retention and enhancing biodiversity. Reforestation initiatives restore degraded land, improving long-term agricultural viability.

5. Soil Moisture Conservation: Techniques such as mulching, terracing and contour farming help retain soil moisture and reduce water loss through evaporation. These methods are crucial in dry and arid regions facing water shortages.

The Future of Soil and Water in Food Production

1. Technological Innovations in Agriculture

Advances in precision agriculture, soil sensors and AI-driven water management systems are revolutionizing food production. These technologies enable farmers to optimize resource use and improve efficiency.

2. Policy and Governance

Government policies promoting sustainable land use, water conservation and pollution control play a critical role in preserving soil and water resources. International collaborations and regulations can ensure long-term food security.

3. Community Involvement and Awareness

Encouraging farmers and communities to adopt sustainable practices through education and incentives is key to preserving soil and water resources for future generations.

Conclusion

Soil and water are indispensable resources for global food production, supporting plant growth, maintaining ecosystems and sustaining human livelihoods. However, challenges such as soil degradation, water scarcity and climate change threaten agricultural sustainability. Implementing sustainable farming techniques, efficient irrigation and conservation practices can safeguard these resources for future generations. Governments, scientists and communities must work together to ensure the responsible use and preservation of soil and water to secure food production in an ever-growing world.

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LIVESTOCK DISEASES DURING SEASON CHANGE--CHALLENGES, RISKS, AND PRACTICAL SOLUTIONS

Introduction

Seasonal change in Punjab goes beyond just temperature shifts—it creates a biological stress point for livestock. As the state goes through its typical cycle of hot summers, humid monsoons, and cold winters, animals experience fluctuations in temperature, humidity, feed availability, and pathogen exposure. These environmental stresses weaken their immunity and significantly increase the likelihood of disease outbreaks. For a sector where livestock contributes substantially to rural livelihoods, these seasonal disease challenges directly affect milk yield, reproduction, growth, and farm economics. This article, written from the perspective of a veterinarian and postgraduate student, aims to provide farmers with a clear understanding of why diseases rise during seasonal transitions, the major illnesses observed in Punjab, and practical preventive strategies that can safeguard animal health and farm productivity.

1. Why Seasonal Change Puts Livestock at Risk?

1.1 Temperature and Humidity Fluctuations: Punjab's climate fluctuates sharply between seasons. Sudden shifts such as warm days followed by cold nights or hot temperatures turning humid with early monsoon showers disturb thermoregulation in animals. This alters metabolic processes and weakens immune responses, making livestock susceptible to infections, especially respiratory and digestive diseases.

1.2 Increase in Vector Populations: Seasonal transitions favor the rapid multiplication of ticks, flies, and mosquitoes.

- **Monsoon and post-monsoon months** see a surge in ticks, leading to tick-borne diseases.
- **Stagnant water** increases mosquito breeding.
- **Warm, humid barns** encourage flies, raising the risk of mastitis and wound infections.

1.3 Changes in Feed and Water Quality

During monsoon and winter, fodder may become:

- Moist or fungal-infested, Nutrient-deficient, Difficult to digest Similarly, contaminated water sources become common during rains. All these factors collectively predispose animals to digestive and metabolic disorders.

1.4 Stress from Housing Conditions

Sudden rainfall, temperature drops, or cold waves often catch farmers unprepared. Animals kept in poorly ventilated, damp, or overcrowded sheds experience higher levels of stress, enabling pathogens to proliferate and spread rapidly.

2. Major Diseases Seen During Seasonal Transitions in Punjab

3. Probable Poisonings During Seasonal Change — An Overlooked Threat

Apart from infectious and metabolic diseases, **seasonal transitions significantly increase the risk of livestock poisoning** in Punjab. This happens due to changes in fodder availability, storage conditions, use of pesticides, and accidental ingestion of toxic materials.

3.1 Nitrate and Nitrite Poisoning (Green Fodder)

Common after early rains or cloudy weather when plants accumulate nitrates especially:

Oats, Sorghum, Maize, Beet tops. Excess nitrates convert to nitrites in the rumen → block oxygen transport → sudden death.

Signs: Breathing difficulty, bluish gums, sudden collapse.

3.2 Urea Poisoning

Occurs when farmers feed excess urea-based supplements during winter or fodder shortage. Improper mixing of urea in feed also leads to toxicity.

Signs: Frothing from mouth, bloat, tremors, rapid death.

3.3 Pesticide and Organophosphate Poisoning

During cropping seasons (especially wheat and paddy), animals get exposed to sprayed crops, stored chemical containers, contaminated fodder, or water. This type of poisoning peaks during **spring and post-monsoon** when farmers spray fields more frequently

Signs: Salivation, muscle twitching, diarrhea, difficulty breathing.

3.4 Mycotoxin Poisoning (Fungal Toxins)

High humidity during monsoon causes fungus growth on stored feed, like: Silage, Moldy grains, and wet fodder. Aflatoxins and other mycotoxins cause liver damage, poor growth, reproductive problems, and reduced milk yield.

Signs: Dullness, diarrhea, reduced immunity, sudden drop in production.

3.5 Heavy Metal and Contaminated Water Poisoning

After heavy rainfall, runoff water may carry contaminants such as fertilizers, Industrial effluents, old batteries, or metallic waste. Animals drinking stagnant or runoff water develop digestive and neurological symptoms.

3.6 Plant Poisoning

During fodder scarcity at season change, animals may consume toxic plants, such as Lantana, Castor bean, and Wild mustard. These cause photosensitivity, diarrhea, liver problems, and even death.

3.7 Rodenticide Poisoning

Rodenticides are widely used during winter storage periods. Animals ingest poisoned bait accidentally or eat dead rodents.

Signs: Bleeding, weakness, pale gums.

Preventing Seasonal Poisonings

- Avoid feeding wet or moldy fodder.
- Store grains and silage in dry, clean areas.
- Do not graze animals immediately after pesticide spraying.
- Mix urea thoroughly or avoid it without veterinary guidance.
- Test water quality after heavy rains.
- Remove toxic plants from grazing areas.

Quick veterinary intervention is crucial in suspected poisoning cases—delays can be fatal.

4. Early Warning Signs During Season Change

Farmers should observe for:

- Fever or chills
- Reduced appetite or water intake.
- Loose stools or frequent coughing
- Pale or yellow eyes (tick fever or anemia)
- Sudden milk drop
- Lameness or foot wounds
- Unusual salivation or frothing (possible poisoning)
- Sudden collapses or deaths

Spotting symptoms early prevents serious complications.

5. Prevention and Management Strategies for Farmers

5.1 Housing Management

- Maintain dry bedding and proper ventilation.
- Protect animals from cold drafts in winter.
- Improve drainage around sheds.
- Disinfect regularly to reduce pathogen load.

5.2 Feeding Strategies

- Introduce new feeds gradually.
- Avoid moldy or spoiled fodder.
- Use mycotoxin binders during monsoon.
- Provide mineral mixtures and balanced rations.

5.3 Water and Sanitation

- Provide clean, fresh water daily.
- Avoid stagnant or runoff water.
- Clean water tanks weekly.

5.4 Vector Control

- Use acaricides, repellents, and fly traps.
- Keep surroundings clean.
- Remove standing water.

Category	Major Diseases / Problems	Key Signs	Seasonal Triggers	Impact / Notes
Respiratory Diseases	BRD complex, Pneumonia, Viral respiratory infections	Cough, nasal discharge, fever, labored breathing, loss of appetite, drop in milk yield	Cold drafts, sudden temperature dips, high humidity in sheds	Most common during winter and monsoon; rapid spread in poorly ventilated sheds
Gastrointestinal Diseases	Diarrhea (calves & adults), indigestion, bloat, ruminal acidosis, parasitic GI infections, fungal/mycotoxin poisoning	Diarrhea, dehydration, poor growth, dullness, bloating, reduced feed intake	Monsoon humidity, contaminated fodder, stagnant water, sudden feed changes	High mortality in calves; major drop in productivity; mycotoxins cause long-term losses
Mastitis (Udder Infections)	Subclinical & clinical mastitis	Swollen udder, clots in milk, pain, fever, reduced milk yield	Wet bedding, humid monsoon, dirty milking conditions, fly burden, cold stress	Severe economic losses; affects milk quality and quantity
Skin & Foot Diseases	Foot rot, dermatitis, maggot wounds, mange, lice, fungal infections	Lameness, foul smell, itching, hair loss, wounds	Excessive moisture, unclean flooring, muddy areas	Reduces feed intake, weight gain, and milk yield; chronic lameness common
Tick-Borne Diseases	Theileriosis, Babesiosis, Anaplasmosis	High fever, pale/yellowish eyes, weakness, sudden milk drop, weight loss	Ticks peak during monsoon & post-monsoon	Require quick diagnosis; high mortality if untreated
Reproductive Disorders	Retained placenta, metritis, repeat breeding, low conception rate	Delayed heat, foul discharge, weak calves, infertility	Heat stress, cold stress, poor nutrition, weakened immunity	Leads to long calving intervals and economic losses
Poultry Diseases	Coccidiosis, CRD, Newcastle disease (unvaccinated flocks), wet litter infections	Diarrhea, respiratory distress, reduced egg production, mortality	Temperature fluctuations, high humidity, poor ventilation, wet litter	Heavy losses in commercial and backyard poultry; requires strict biosecurity

5.5 Vaccination and Deworming

- Follow state-wise vaccination guidelines. Ensure **vaccines are up to date** (e.g., FMD, HS, BRD-related vaccines as advised locally).
- Deworm strategically before monsoon and after winter.
- Maintain accurate records.

5.6 Isolation Practices

- Separate new or sick animals for 10–14 days.
- Use dedicated feeding equipment for them.
- Disinfect isolation areas afterward.

6. Management During Disease or Poisoning Outbreaks

Immediate Actions

- Isolate affected animals.
- Provide clean bedding, warmth, and hydration.
- Do not give random medicines or antibiotics.
- Call a veterinarian promptly.

Veterinary Intervention

Seek urgent help if signs include:

- Severe diarrhea
- High fever
- Difficulty breathing
- Nervous signs
- Bleeding
- Sudden weakness
- Signs of poisoning

Conclusion

Seasonal change in Punjab brings predictable disease patterns—and hidden risks such as poisoning due to feed changes, pesticide exposure, and poor-quality fodder.Farmers who understand these challenges and adopt preventive measures can dramatically reduce livestock losses. With simple steps like improving housing, ensuring clean fodder and water, controlling vectors, vaccinating regularly, and monitoring animals daily, farmers can keep their livestock healthy and productive throughout the year. Early recognition and veterinary care remain key to preventing major losses.

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USE OF ROW COVERS IN VEGETABLE PRODUCTION

Introduction

Protected cultivation is technique used to modify plant's natural environment in order to optimize plant growth. Such techniques are often used to protect plants from frost in order to extend the growing season of a crop. Row covers are generally made of flexible transparent to semitransparent materials. They are used to enclose one or more rows of plants in order to enhance crop growth and production by increasing both air and soil temperatures and reducing wind damage (Hochmuth *et al.*, 2000). Row cover creates favorable microclimate for the growth of vegetable crops.

Crop covers are used for many reasons including, season extension (frost protection), insect exclusion, heavy rain, and hail protection. When the main objective of row covers is to increase temperature, it is important to understand several factors including: advantages, row cover type, material used, level of temperature increase, and frost protection ability.

How to use row covers

- Drape it over and enclose plants - individuals, rows, groups, or entire beds - and secure it to the ground with sod pins, boards, bricks, sandbags, rocks, or soil.
- The row cover can lie directly on the crop- hence the name "floating row cover." The growing plants push the cover upwards if you give it enough slack.
- Alternatively, you can erect simple frames using wood, PVC pipe, #9 wire, or other available materials to support the row cover above your plants. This is recommended when using medium-weight and heavyweight row covers.

- Buy or make plastic snap clamps and clips to secure row covers to a PVC pipe frame.
- Provide frost protection in the spring and even greater protection in fall (from soil warm-up) due to increased temperature under the cover; reduce cold damage to overwintering crops.
- More rapid plant establishment and growth in the spring and fall due to higher temperature (air and soil) and humidity under the cover.
- Row covers can reduce the time between flowering and harvest and increase harvests per unit area.
- Creates a shield around your plants keeping insect pests, mites, rabbits, deer, birds, and groundhogs from feeding on your plants. Some of the insect pests excluded- squash vine borer, squash bug, cucumber beetles, flea beetles, Colorado potato beetle, harlequin bug, Mexican bean beetle, aphids. It must be installed over plants soon after planting to be effective against pests.

When to Use & Remove covers

- **1. Early Season:** Plant cool-season crops (kale, cabbage) early; warm-season crops (peppers, tomatoes) to protect from late frosts.
- **2. Summer:** Remove when temperatures exceed 90°F (risk of heat stress) or when plants need pollination (cucumbers, squash, peppers).
- **3. Pollination:** For insect-pollinated crops, remove covers during the day when bees are active.

Types & Application

1. Floating Row Covers: Lightweight fabric laid directly on plants or supported by hoops, often porous polypropylene.

2. Hoop-Supported (Low Tunnels): Fabric draped over hoops (PVC, wire) to create tunnels, often clear plastic.

3. Weight Matters: Lighter covers allow more light (85%), heavier ones offer more frost protection (6-8°F) but less light (70%).

Benefits of row covers

1. Frost protection

Depending on the material, row covers can deliver a frost protection factor of 2–7°F. Generally, the heavier materials (spun bonded polypropylene) give greater frost protection but tend to exclude more light. Row covers can also be used with some crops in the fall for late frost protection.

2. Early yield

The greenhouse effect of most row covers will not only warm air surrounding the plant but will also result in warmer soil temperatures, enhancing seed germination, root growth, shoot growth, and maturity. Early crop production generally results in higher crop prices at local markets. When combined with black plastic mulch, many crops may mature one to three weeks earlier than under normal cropping practices. However, increased costs generally limit use to high-value horticultural crops.

3. Increased yield

Many cucurbits (squash, cucumbers, melons) respond well under row covers, with increased yields of as much as 25% (Helbacka, 2002). Earlier production of cool-season crops like spinach and leaf lettuce will also increase total yields. Earlier cane growth of ever bearing red raspberries in the spring will result in earlier production in late summer to early fall and increased total yields for areas of New Mexico with a short growing season. Other crops that have responded well to row covers include tomatoes, peppers, eggplant, cauliflower, strawberries, sweet corn, Cole crops, and peas.

4. Wind protection

Row covers supported with wire hoops will protect crops from wind and blowing sand. This will result in less plant stress and reduced desiccation of delicate early growth. Row covers will also protect crops from hail and pounding rain. However, unsupported floating row covers can rub on plants and damage the leaves, stems, or flowers.

5. Pest control

Lightweight floating row covers are often used to cover some crops in the spring to protect them from insects. Edges of the cover must be covered with soil to ensure exclusion of insects. This will result in less use of insecticides and less frequency of insect-borne diseases. Floating and supported row covers can also be used to protect plants from birds.

6. Water conservation

Less irrigation may be required under row covers since water collects as condensation on the inside of the cover and returns to the soil. Less crusting occurs since wind movement and water evaporation are reduced. However, overall water use may increase since crop growth is earlier and greater and occurs over a longer period of time.

Review of literature

Hernandez *et al.* (2004) recorded maximum biomass (709.6 g/m^2), total yield (13.8 kg/m^2) and commercial yield (11.9kg/m^2) whereas lowest tip burn affected plants (1.0 ± 0.5 %), bolted plants (1.2 ± 0.5%), non-heading plants (4.6 ± 1.2%) and deformed heads (4.6 ± 1.24%) were found with the use of row cover in Chinese cabbage *cv*. Nagaoka 50.

Kalisz *et al.* (2014) observed maximum height (24.1cm), leaf number (17.3), leaf area (392.3cm^2), leaf length (31.3cm) and leaf width (21.1cm), total yield (90.20 t/ha), total number of heads per hectare (71429) while marketable yield (88.05 t/ha) and number of marketable heads per ha (68452) were recorded with the application of row cover in Chinese cabbage *cv*. Optiko F1.

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BIOTIC AND ABIOTIC POLLINATION: THE CRITICAL ROLE OF INSECTS IN SUSTAINABLE AGRICULTURE

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WHAT IS POLLINATION?

Pollination is described as the process in which pollen is transferred from male anthers to female stigmata, either inside the same flower (self-pollination) or between plants (cross-pollination) (Sukumaran *et al*, 2020; Garcia breijo *et al*, 2020). Pollinators are critical components of the crop production process since plants are entirely depending on vectors to transmit pollen during cross-pollination (MacInnis and Forrest, 2020). Possible vectors which are responsible for pollination include water and wind, while in animal pollinators, bats, birds, and insects are of great importance (Lobo *et al*, 2005; Zeng and Fisher, 2020; Kooi and Ollerton, 2005). Two categories of pollination exist based on the roles that living and non-living methods play in the process.

There are following pollination methods:-

ABIOTIC POLLINATION:

Abiotic pollination uses non living methods such as wind and water to move pollen from one flower to another. This allows the plant to spend energy directly on pollen rather than on attracting pollinators with flowers and nectar.

There are following abiotic agents involved in abiotic pollination:

Water: Pollination by water is called **hydrophily,** uses water to transport pollen, sometimes as whole anthers; these can travel across the surface of the water to carry dry pollen from one flower to another. In *Vallisneria spiralis,* an unopened male flower floats to the surface of the water, and, upon reaching the surface, opens up and the fertile anthers project forward. The female flower, also floating, has its stigma protected from the water, while its sepals are slightly depressed into the water, allowing the male flowers to tumble in (Ackerman, 2000).

Wind: Pollination by wind is called **anemophily,** mostly 98% of pollination is done with the help of wind. This probably arose from insect pollination, most likely due to changes in the environment or the availability of pollinators. The transfer of pollen is more efficient than previously thought; wind pollinated plants have developed to have specific heights, in addition to specific floral, stamen and stigma positions that promote effective pollen dispersal and transfer (Ackerman, 2000).

Rain: Pollination by rain splashes is called **ombrophily,** has been proposed as a floral strategy. During rainfall, raindrops physically flicked away the anther cap exposing the pollinarium.

Rain drops then caused pollination by ejecting upwards with strap like stipe, pulling them back and causing them to fall into the stigmatic cavity, resulting in self-pollination (Daumann, 1970).

BIOTIC POLLINATION:

Approximately 67% of flowering plants depend on insects for pollination, with the remainder relying on birds and mammals (Tepedino, 1979: Levin, 1971). Insect pollinators, primarily dominated by bees, include a diverse group such as butterflies, flies, moths, beetles, and ants. Bees and flies pollinate over 90% of the world's major plant species, while other pollinators visit less than 6% of crops (Michener, 2007). Plant-pollinator interactions are ecologically vital, as many plants rely on pollinators for reproduction. Insect pollination is crucial for sustainable agriculture and maintaining ecological balance (Kearns, 1998). The pollination carried by various insects are classified as:

Canatharophily (Beetle pollination): Beetles are important anthrophiles, having robust body, also known as destructive pollinators, feed on floral parts or the pollen directly. More than 380,000 species of beetles are assumed to pollinate 90% plants. Beetles are generally attracted to flat or disc-shaped large, pale white, cream or green flowers, having carrion like scent.

Melittophily (Bee pollination): bees are able to access more complicated floral forms, even those that require complicated floral handling. For example, flowers in the pea family (Fabaceae). Bees generally preferred highly scented, yellow, blue, or purple colour flowers for rewards, allowing an additional chemical sensory way for bees to locate them. Many bee-pollinated flowers have nectar guides, areas of colour that highlight the location where they nectaries are located. Nectar and pollen is high-energy carbohydrate food source for adult bees, and this powers their metabolically expensive flight. For this reason, bee-pollinated flowers provide abundant nectar and pollen.

Psychophily (**Butterfly pollination):** Flowers pollinated by butterflies are commonly disc shaped or their structure provide an easy landing pad. Members of the family Asteraceae are widely visited by butterflies. Butterflies are sun-seekers, having basking behavior, commonly attracted to highly scented pink, red, or purple, flowers. Nectaries can be located in tubes that are accessible by long proboscis. The anthers of butterfly-pollinated flowers are usually located in places that would deposit pollen on the heads or undersides of butterflies. A common group of specialized butterfly-pollinated plants are the milkweeds which have colourful, clustered, and tubular flowers.

Phalaenophily (**Moth pollination):** Flowers pollinated by moths are white, or cream coloured, share some characteristics with butterfly-pollinated flowers, including nectaries in deep spurs, more perfumed and attractive. Most moths are active in the evening, or at dawn and dusk (crepuscular), their flowers are generally less colourful. The amount of nectar produced is relatively high.

Myophily (**Fly pollination):** Pollinating flies that feed on nectar are attracted to a similar variety of floral types as bees are attracted to. Fly-pollinated flowers tend to display a diversity of colours and shapes, although they tend not to be as complex as those visited by bees. The scent emitted by these flowers is also usually quite fragrant and potent to aid flies in locating the flowers. Flies are nectar feeders, and fly pollinated flowers provide ample nectar.

Sapromyophily (Fly pollination by carrion or dung seekers): Flowers pollinated by flies seeking animal flesh or dung as egg-laying substrates is called sapromyophily. They are heavily scented to mimic foul odours. The flowers can be small, colourless, or a dull purple/pink, with a sticky secretion. For example- Trap-blossoms, Giant corpse plant, or titan arum, *Amorphophallus titanum*. The flower produced by this arum produces a strong, foul rotting flesh like odour which attracts flesh flies and carrion beetles and trapped inside the giant flower until it wilts, releasing them after they have been covered in pollen (Wojjick, 2021).

Myrmecophily (Ant pollination): Ants are minor pollinators of arid and alpine environments and flowers pollinated by ants are small, often occurring in clumps, located at the base of stems. Ants feed on nectar found inside of the flowers as well as on extra-floral nectaries. Examples- Small's stonecrop (*Diamorpha smallii*), alpine nailwort (*Paronychia pulvinata*), and Cascade knotweed (*Polygonum cascadense*), as well as two alpine orchid species, Chamorchis alpine and *Dactylorhiza viridis*. (Wojjick, 2021).

Role of pollination in agriculture and food production

Pollinators are vital for agriculture, affect a **35% of the agricultural production in the world**, contributing to one-third of the food we eat and over $153 billion annually (Gallai *et al*, 2009). When considering the top 15 crops contributing to the human diet globally in 2013, slightly over **10%** of the total human diet of plant crops (211 out of 1916 kcal/person/day) is dependent upon insect pollination (FAO, 2017). While wind pollinates staple crops like corn and wheat, about 80% of global crops depend on pollinators (Hrisov *et al*, 2020). Bees and flies are the primary pollinators, though moths, wasps, and beetles also play important roles, especially in tropical regions (Breeze *et al*, 2011). Honey bees, bumble bees, and specialized bees like squash and mason bees pollinate many fruits, vegetables, and legumes (Gill *et al*, 2016). Flies pollinate crops such as cocoa, coffee, and various tropical fruits, while moths, wasps, and beetles contribute to crops like yucca, figs, and pomegranates (McGregor, 2009).

Conclusion- Pollination is vital for ecosystem balance and agricultural productivity, involving both abiotic (wind, water) and biotic (insects, birds, mammals) agents. Insects, especially bees and flies, are key pollinators, with over 80% of global crops relying on their services. This process enhances crop quality and quantity, contributing to global food security and the economy. However, threats like habitat loss and pesticide use endanger pollinators, posing risks to agriculture and biodiversity. Preserving pollinators is crucial for maintaining ecological balance and ensuring a sustainable food supply, requiring conservation efforts, public awareness, and supportive policies to protect these essential species.

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BIOPESTICIDES AS GREEN DEFENDERS: MODE OF ACTION AND IMPORTANCE IN SUSTAINABLE AGRICULTURE

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Abstract

Biopesticides are often regarded as green defenders because they safeguard agricultural produce while minimizing ecological harm. They represent an environmentally benign alternative to conventional chemical pesticides. These products include a wide array of bioactive molecules derived from microorganisms and other natural sources, as well as genetically engineered crops in which protective DNA sequences are stably incorporated to enhance innate resistance to pest attack. Biopesticides contribute significantly to both agricultural productivity and public health protection. They are generally classified into three major categories and encompass entomopathogenic viruses, bacteria, fungi, nematodes, and diverse plant secondary metabolites. Owing to their ecological compatibility, these agents are becoming increasingly important in replacing or supplementing synthetic pesticides and form a critical component of modern pest management systems. A central focus of ongoing biopesticide research is the formulation of affordable, farmer-accessible products that can be effectively deployed at the field level. Such advancements will enable wider adoption of biopesticides within Integrated Pest Management (IPM) programs, thereby reinforcing sustainable agricultural practices. This article highlights the major classes of biopesticides, their specific groups and modes of action (MOA), and their overall significance in contemporary crop protection.

Introduction

During the Green Revolution, widespread use of synthetic pesticides boosted crop productivity but caused significant environmental harm and health risks. Repeated and injudicious use of these pesticides has led to pest resurgence, resistance issues. They also pose a significant risk of contaminating the food chain by leaving residue of pesticides, harming non-target organisms such as pollinators, birds, fish, and beneficial microbes. Moreover, exposure to these pesticides can lead to acute health issues like skin, respiratory, gastrointestinal, and nervous system problems. Agricultural workers, rural communities, and populations near pesticide production and waste sites are particularly vulnerable to these adverse effects (Sinan 2025).

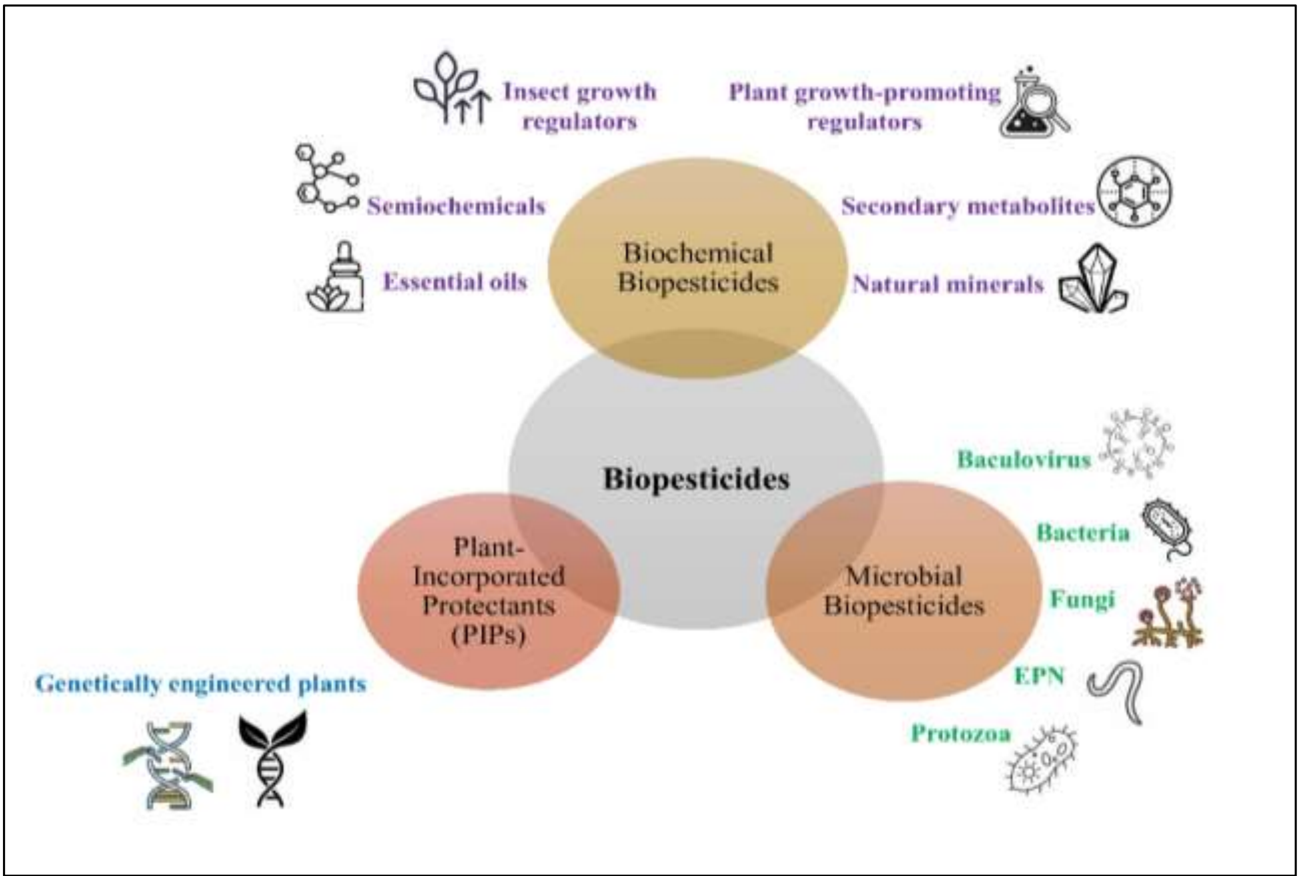

Fig 1 Categories of biopesticides

Biopesticides, often regarded as green defenders, represent a rapidly advancing class of pest-management agents derived from natural biological sources. They offer an eco-compatible alternative to synthetic chemicals by targeting pests with high specificity while minimizing harm to beneficial organisms and the broader environment (Kumar and Singh 2015). These products encompass microorganisms, plant-derived metabolites, and genetically incorporated protective traits that collectively enhance crop resilience. Their diverse modes of action ranging from infection and toxicosis to enzymatic disruption and induced systemic resistance enable precise suppression of insect pests, pathogens and weeds (Chandler et al 2011) Unlike conventional pesticides, biopesticides degrade quickly, leaving minimal residues and reducing ecological toxicity. Collectively, biopesticides contribute to resilient agricultural ecosystems (Thakore 2006). Within Integrated Pest Management (IPM) frameworks, biopesticides serve as essential components, providing targeted pest suppression while lowering dependence on synthetic chemicals (Abrol and Sankar 2015).

Biopesticides and Their Categories

Agriculture is challenged by a wide range of pests including insects, pathogenic fungi, and numerous weed species that severely impair plant health and reduce overall crop productivity. Although chemical pesticides have helped mitigate these issues their excessive and prolonged reliance has created serious environmental concerns (Gupta and

Dikshit 2010). They serve as a crucial link between eco-friendly technologies and sustainable farming practices. According to recent updates from the U.S. Environmental Protection Agency (EPA), fifteen new biopesticide active ingredients have been registered since January 2025, and biopesticides are classified into three main categories (Fig 1).

1. Biochemical Biopesticide: A biochemical pesticide is formulated from naturally derived, low-toxicity compounds that manage pests through non-lethal modes of action such as influencing their behaviour, development or physiology, instead of causing direct mortality and provide natural ecofriendly management. Examples include essential oils (EOs), semiochemicals (allelochemicals and pheromone), plant growth-promoting regulators (rhizobacteria), insect growth regulators (juvenile hormones and chitin synthesis inhibitors), secondary metabolites, as well as natural minerals (diatomaceous earth, kaoline) (Singh et al 2021).

EOs are volatile plant secondary metabolites extracted via steam or water distillation, containing lipophilic compounds that penetrate insect bodies to disrupt their nervous system and enzymes, causing death. EOs from families like Asteraceae, Myrtaceae, Apiaceae, Lamiaceae, and Rutaceae act as repellents, fumigants and insecticides against pests across major insect orders. Specific oils (e.g., coriander, caraway, neem, basil) contain compounds like linalool, carvone, and camphor, which show strong toxicity or repellency to various pests (Mossa 2016). Semiochemicals regulate insect behaviour by disrupting lipid biosynthesis, juvenile hormone receptors, moulting and chitin synthesis. They include pheromones, which mediate communication within the same species, and allelochemicals, which affect behavior between different species. They used in IPM through pest monitoring, trapping, mating disruption, and push-pull strategies (Jindra and Bittova 2020). Plant Growth-Promoting Rhizobacteria (PGPR), including genera like Pseudomonas and Bacillus Agrobacterium, Streptomyces etc enhance plant nutrition, induce secondary metabolites and trigger Induced Systemic Resistance (ISR) via jasmonic acid and ethylene signalling pathways which increase plant defenses against herbivorous insects (Van de Mortel et al 2012). Insect growth regulators (IGRs) interfere with insect development by mimicking juvenile hormones or inhibiting chitin synthesis, causing mortality and reproductive disruption. Synthetic juvenile hormone analogues (e.g., methoprene) and chitin synthesis inhibitors (e.g., diflubenzuron) offer selective, low-toxicity pest control, though often slower acting (Liu and Stansly 2004). Mineral-based insecticides such as kaolin, insecticidal soaps, and diatomaceous earth control pests physically by damaging cuticles or causing desiccation, providing environmentally safe options through mechanical effects rather than chemical toxicity (Lengai and Muthomi 2018).

2. Microbial Pesticides: These include microorganisms like bacteria, fungi, viruses, protozoa, or nematodes and their derived metabolites to control specific pests. Microbial bioactive metabolites act by infecting, parasitizing, or producing toxins that target insects, weeds, plant pathogens, or other harmful organisms (Verma et al 2024). Microbial biopesticides, in particular, offer developing nations a valuable opportunity to explore and harness indigenous biopesticide resources for effective crop protection (Nathan 2014). Biopesticides derived from bacteria such as Bacillus thuringiensis (Bt), as well as from fungi, viruses, protozoa, and certain nematodes, exhibit high target specificity and contribute to ecologically resilient pest management (Grewal et al 2005).

2.1 Bacteria (Bacillus thuringiensis,

Pseudomonus fluorescens): The mode of action of entomopathogenic endospore-forming soil bacterium, Bt involves the ingestion of crystalline δ-endotoxins (Cry proteins) by insect larvae, which then dissolve and activate in the alkaline environment of the insect midgut (Kumar 2012). These activated toxins bind to specific gut epithelial receptors, creating pores in the cell membranes. This leads to midgut cell lysis, gut paralysis, septicemia, and ultimately death of the target insect (Aronson and Shai 2001).

2.2 Fungi (Metarhizium anisopliae, Beauveria bassiana, Trichoderma viride, Verticillium lecanii): Fungal pathogen initiates infection by attaching its conidia to the insect cuticle, where they germinate and develop penetration structures. The fungus produces a range of cuticle-degrading enzymes, such as chitinases, proteases and lipases, enabling it to breach the integument and enter the hemocoel (Vey et al 2001). Once inside, it multiplies as blastospores and synthesizes toxic metabolites like destruxins that weaken the insect's immune system and disturb vital functions. The host eventually succumbs to systemic infection and tissue breakdown, after which the fungus emerges from the cadaver and sporulates to continue its life cycle.

2.3 Virus (Baculovirus): Baculoviruses infect larvae only after ingestion, where the occlusion bodies dissolve in the alkaline midgut, releasing virions that invade midgut epithelial cells. The virus then replicates and spreads systemically, although in some hosts the infection remains confined to the midgut or fat body. Nuclear Polyhedrosis Virus (NPVs) release multiple virions per occlusion body, whereas Granulosis Virus (GVs) typically release a single virion. The occlusion bodies protect the virus in the environment, enabling successful transmission between susceptible larvae (Rohrmann 2013).

2.4 Nematode (Heterorhabditis, Steinernema): Nematodes infect insects when third-stage infective juveniles enter through natural openings such as the mouth, anus, or spiracles. Once inside the hemocoel, they release symbiotic bacteria that rapidly multiply and induce septicemia, killing the host within 24–48 hours. After host death, the nematodes reproduce and generate a new cohort of infective juveniles to continue the cycle (Hughes and Wood 1981).

2.5 Protozoa (Nosema): Protozoan pathogens such as Nosema spp. infect insects when their spores are ingested and germinate in the midgut, releasing sporoplasms that invade host cells. Inside these cells, they multiply extensively, destroying tissues and disrupting organ function (Solater and Becnel 2000). As infection progresses, new spores form and are shed into the environment, where they infect additional hosts and may be spread by parasitoids or predators.

3. Plant-incorporated protectants (PIPs): These consist of pesticidal proteins like Bt-derived Cry toxins that are synthesized inside genetically modified plants (Sanahuja et al 2011). Other PIPs include vegetative insecticidal proteins (Vips), bacterial toxic complex proteins from Xenorhabdus and Photorhabdus, enzyme inhibitors such as α-amylase inhibitors, baculovirus proteases and RNA interference molecules like dsRNA which targeting essential insect genes. Cry protein PIPs kill pests by binding to specific receptors in the insect midgut, forming pores that cause cell lysis and death. Different Cry proteins target specific insect groups, such as Cry1 for Lepidoptera and Cry3 for Coleoptera. dsRNA PIPs work by entering pest cells after ingestion, where they trigger RNA interference to degrade essential mRNA, disrupting vital protein production and causing pest death or reduced growth. The first approved dsRNA PIP targets the corn rootworm by disrupting the Snf7 protein

(Parker and Sander 2017). These diverse molecules specifically target insect pests through multiple modes of action, offering targeted, environmentally safer pest control inside the plant (Ganapathy et al 2021).

Importance of Biopesticide in Sustainable Agriculture

Biopesticides play a crucial role in sustainable agriculture as they provide eco-safe options compared to traditional chemical pesticides. They act selectively against target pests, helping conserve beneficial fauna and thereby supporting natural ecosystem functions. Due to their rapid degradation in natural environments, biopesticides reduces risk of contamination to soil, water bodies, and harvested produce (Fenibo et al 2022). Owing to their varied mechanisms of action, biopesticides also reduce the likelihood of pests developing resistance, ensuring long-term effectiveness. When incorporated into IPM systems, they lower reliance on synthetic pesticides. However, their effectiveness in the field can be variable, often requiring higher doses, which are influenced by factors such as plant species, extraction techniques, and environmental conditions. Other challenges include short shelf life, high formulation costs, lack of standardized testing, limited production facilities in developing regions, regulatory hurdles, and low awareness among farmers. Despite these challenges, biopesticides foster healthier soils and greater biodiversity by avoiding the harmful effects associated with broad-spectrum chemicals. These benefits make biopesticides a key component of environmentally responsible and sustainable crop protection. Additionally, biopesticides hold a strong future potential as demand grows for safer, residue-free crop protection solutions. Advancements in biotechnology and formulation technologies will enhance their efficacy, stability, and field performance. Their integration into precision agriculture and IPM systems is expected to strengthen sustainable pest management globally, providing safer alternatives that benefit human health and the environment with future potential through improved formulations and policy support for IPM integration.

Conclusion

Biopesticides emerge as an eco-safe alternative of synthetic pesticides. Although challenges exist, their use in integrated pest management helps to prevent pest resistance. Biopesticides are indispensable in promoting sustainable agriculture practices. Their continued research, formulation improvement are crucial role for global transition to resilient and sustainable food systems.

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ECONOMICS OF STAGES OF SEED MULTIPLICATION/PRODUCTION

Abstract

Seed is the fundamental input in agriculture and a key determinant of crop productivity. The process of seed multiplication ensures that genetically pure, high-quality planting material is available in sufficient quantity and at affordable prices for farmers. Seed multiplication follows a structured, multi-stage system—beginning with nucleus seed and extending to certified or quality seed. Each stage has distinct economic implications, influencing costs, risks, and profitability across the seed value chain.

Introduction

Agricultural productivity largely depends on the availability and quality of seed. Studies indicate that seed alone contributes to around 15–20% of yield improvement, and when combined with complementary inputs, the contribution can rise to 45% or more (Louwaars & de Boef, 2012; Singh *et al.*, 2019). To meet this demand, seed systems employ a structured process of multiplication, involving several stages designed to maintain genetic purity, physical quality, and viability. Each stage carries unique economic characteristics, affecting costs, risks, and benefits for breeders, seed agencies, and farmers.

Stages of Seed Multiplication and their Economics

a) Nucleus Seed

Nucleus seed represents the purest form of a variety, produced and maintained by plant breeders. It is the first stage in the formal seed chain, produced in very small quantities.

- **Economic aspects:** Production costs are high due to breeder involvement, controlled environments, and rigorous monitoring (FAO, 2006). However, it is not commercialized, serving only as the base material for subsequent multiplication stages.

b) Breeder Seed

Produced directly from nucleus seed, breeder seed is generated under strict supervision by the joint inspection team of scientists and officials of certification agency and National Seed Corporation

- **Economic aspects:** Costs remain high due to isolation and inspection requirements. Breeder seed is distributed primarily to government seed corporations or private multipliers, forming the backbone for foundation seed production (ICAR, 2015).

c) Foundation Seed

Derived from breeder seed, foundation seed is produced under official certification to maintain purity and identity.

Economic aspects: The per-unit cost declines compared to earlier stages because of larger-scale production, but expenses for certification, rouging, and field inspections remain significant. Foundation seed is sold to seed producers for certified seed production, generating moderate profitability (Maredia *et al.*, 1999).

d) Certified Seed

Certified seed is produced from foundation seed and directly supplied to farmers. This stage represents large-scale commercial production.

Economic aspects: Costs include seed contracts with growers, field monitoring, post-harvest processing, storage, and marketing. However, certified seed commands the largest market share and profitability in the seed sector, benefiting from economies of scale (Tripp, 2001).

e) Farm-Saved Seed (Informal System)

Farmers often save a portion of their harvest as seed for the next season.

Economic aspects: While it reduces immediate costs, farm-saved seed often suffers from genetic and physical deterioration, resulting in lower yields. Although dominant in developing countries, its economic viability is increasingly challenged by the productivity benefits of certified seed (Almekinders & Louwaars, 2002).

Economic Analysis Across Stages

1. **Cost Structure:** Per-unit cost is highest at nucleus and breeder seed stages, decreasing progressively at foundation and certified seed stages as scale increases.
2. **Value Addition:** Each stage adds value through genetic assurance, certification, and processing. Certified seed, despite originating from earlier stages, carries the highest commercial value.
3. **Risk Distribution:** Early stages are vulnerable to genetic contamination, while later stages face market and distribution risks.
4. **Profitability:** Breeding institutions recover research and monitoring costs through breeder/foundation seed sales. Seed companies gain profits primarily from certified seed markets. Farmers capture productivity benefits, particularly when adopting hybrid or improved varieties (World Bank, 2007).
5. **Economies of Scale:** Research institutions operate on small scales in the early stages, while commercial seed enterprises exploit large-scale production, processing, and logistics efficiencies at later stages.

Policy and Market Considerations

Seed systems are shaped by the interplay between public and private actors. Public institutions typically dominate early stages, while private firms engage more in certified seed production and marketing (Pray & Nagarajan, 2014). Governments often subsidize breeder and foundation seed to ensure affordability at the farmer level.For example,National mission on oilseeds and oil palm and Rashtriya krishi vikas yojna in Madhya Pradesh Certification systems play a vital role in maintaining market trust and ensuring quality. Adoption rates depend on crop type, farmers' awareness, and the relative profitability of improved seed over farm-saved seed.

Conclusion

The economics of seed multiplication reflects a balance between high-cost, low-scale early stages and large-scale, revenue-generating later stages. While the nucleus and breeder seed stages safeguard genetic integrity, foundation and certified seed production drive commercial viability and farmer adoption. Strengthening seed multiplication systems yields long-term economic benefits for breeders, seed companies, farmers, and national food security.

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REVOLUTIONIZING CULTIVATION OF FODDER OATS WITH AI: ENHANCING YIELD, SUSTAINABILITY AND PROFITABILITY

Introduction

Oats, being a nutritious crop, play an important role as a component of food as well as fodder. Livestock health and production are totally dependent on the quality and quantity of fodder. With the highest livestock population in India and more than 80% deficiency in fodder, a revolution is required for sustaining and enhancing yield as well as profitability. Integrating advanced technologies, such as intelligence automation, algorithm forecasting, and linked devices, can lead to more sustainable and productive farming operations. Artificial intelligence emerged as the easiest solution to govern all the factors together. It provides essential support to crop management, crop monitoring, and other essential agronomic practices for fodder cultivation. AI and Machine learning technology are empowering agriculture to be more data-driven and predictive by analyzing large volumes of data from satellite photos, sensors, and IoT devices to improve crop health, estimate yield, and optimize resource allocation.

Key applications of AI in fodder oat cultivation

Precision farming: AI helps in site specific cultivation, with this the perfect timing and data analysis to optimize the production through various agronomic practices like sowing, irrigation, etc., using sensors, drones or satellite.

Soil health monitoring: AI is the best option for analyzing the initial and final soil health for growing crops along with efficient fertilizer dose for the fodder nutrition as well as promoting sustainable practices with lesser wastage of resources.

Monitoring of crops and diseases prevention: Monitoring systems using AI can detect early signs of disease (for example, blight, rust, etc.), pests, and can help prevent major losses.

Use of automated machineries (Labour-intensive): AI-powered machines perform automated tasks, like sowing, harvesting, spraying etc. reducing labour charges as well as enhancing efficiency.

Predictive analytics for yield optimization: Usage of an intelligent system can analyze soil performances, crop performances, and climatic conditions, leading to the prediction of fodder oat yield, thus helping farmers to make informed decisions. It also helps in the identification and eradication of weeds, anticipating and providing plant disease symptoms and pest control solutions.

Intelligent harvesting techniques: Using cutting-edge technology such as smart sensors, robots, UAVs, IoT devices, and computer vision based on ML and DL models, intelligent harvesting techniques are completely reinventing agriculture and reducing human labour.

Importance and on farm use of AI for cultivating fodder oat

Fodder oat, being a serial crop that to be harvested at the proper succulent stage, requires utmost care and attention along with a keen regular observations,which can result in high labour costs for everyday monitoring. Along with, for proper quality of fodder,the soil supplying nutrients needs to be tested appropriately at intervals, which can help to raise healthy and nutritious fodder, which again leads to proper animal health. Farmers often use excessive amounts of fertilizers such as urea for cereal crops, which is not sustainable, and it's also not possible for them to predict it always, as the soil, climatic conditions varies place to place years to years.

Autonomous crop management can be done through an artificial intelligence algorithm, combining with IoT, sensors monitor soil moisture and environmental conditions, the algorithm decides the real-time of irrigation and sowing.it conserves water and so works sustainably. Machine learning models detects leakage through sensing change in water flow or water pressure in irrigation pipes and avoid losses in advance. Also, computer vision models can enerate accurately soil-related data, by monitoring it properly. Plant science data keeps check in the crop health helping to prevent diseases. Adjustments are automatically done by AI according to the prevailing conditions. It can accurately detect the harvesting stage for fodder with the highest green foliage and having the highest protein content and other nutrients using AI powered machines.AI technology can detect insects and diseases with 90% accuracy, however firstly researchers has to train it with data set for proper algorithm by collecting images.AI powered drones use computerised vision to determine specific pesticide amount to be sprayed on required areas.

Oats being a major rabi cereal fodder crop, requires an optimum temperauture for germination; it becomes very difficult for farmers to predict the proper time.

ML algorithms are used for yield mapping to analyze huge data sets within time.Combination of techniques like 3D mapping, data from drones and sensors can help farmers to predict the fodder yield.Multiple drone flightswere used for data analysis through algorithm enabling more precise result.

All these methods help farmers to take decisions of future fodder yield,also to determine when and where to sow ,and to allocate the resources accordingly with better productivity and profit.

Some of the significant broad leaved weed like *Chenopodium murale*,*Chichorum intybus*,*Lathyrus sativus* and grass weeds like *Cynodon dactylon*, *Cyperus rotundus* causes 10-15% of yield reduction.

AI powered computer vision combining with machine learning analyzes size,shape and colour of leaves to distinguish weeds from oat crop.Further which is used to program robots to carry out robotic automation tasks for example weeding(done through smart bots).Similar smart bots are used for harvesting also making it labour intensive.Fodder oat is harvested between 60- 70 DAS for single cut,but the exact and real time can be accurately analyzed through AI driven technologies.

Conclusion

Fodder oats, being an essential green fodder for enhancement of livestock health and production, requires good care for its high production and profitability, qualitatively and quantitatively. But without exhaustion of the existing resources and preserving it for future. So, automated technologies like AI can help to increase profit, yield also being sustainably.

Big data analytics combining with AI, enables farmers to get the best recommendations based on real-time and accurate information, resulting in more productivity and benefit. Also, it prevents the excessive use of resources thus revolutionizing the whole system and introducing crop cultivation to a new world in a new way.

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Jeevamrit / Jeevamrutha: The base for Natural Farming

Abstract:

With the adverse impacts of intensive green revolution on Indian agriculture, recently the farmers have shown their interest towards the organic and natural farming production systems. Organic concoctions like Jeevamrit/Jeevamrutha which is a microbial culture prepared from the on-farm inputs like cow dung, urine, jiggery and pulse flour has been found a suitable formulation in natural farming to meet the nutritional demands of the crops.

Jeevamrit is a traditional fermented liquid organic concoction commonly used as soil microbial enhancer in natural farming. It is a rich source of Bacteria, fungi, actinomycetes and also contains other beneficial microorganisms. It is claimed that the application of jeevamrit stimulates crop growth and repels some of the insect-pests.

Keywords: *Jivamrit; Organic Concoctions; Natural Farming.*

Introduction of green revolution in Indian Agriculture during 1960s transformed the India to food grain surplus country from the deficit one. Green revolution played a crucial role in the socio-economic development of the Indian people especially the rural India. But the intensive agriculture has led towards a major degradation of the fragile agro-ecosystem especially the Indo-Gangetic Plain of India.

In the recent past, high cost of agricultural inputs and diminishing economic returns have adversely affected the socio-economic conditions of Indian Farmers. Loss of long-term soil fertility, soil erosion, diminishing water resources, soil and water pollution, salinized ground water, higher incidences of human, plant and animal diseases and increased global warming are the major adverse impacts of over exploitation of agricultural technologies adopted during Green Revolution (Rahman, 2015).

Because of the above-mentioned adverse impacts of intensive agriculture, organic farming and natural farming which is also known as the Bhartiya Paramparagat Krishi (BPK) are gaining popularity among the farmers.

Use of on farm inputs, less/no dependency on off farm inputs and no/reduced use of external synthetic agro-inputs not only helps in decreased cost of cultivation but also maintain the long-term soil fertility and biodiversity. Adoption of indigenous knowledge along with intercropping in natural farming has been proven a scientific practice for economic benefits of farmers, especially in the adverse weather conditions.

The concept of natural farming is four major pillars and these are as follows:

a. Jeevamrita / Jivamrutha / Beejamrita / Beejamrutha
b. Acchadana/mulching
c. Intercropping of legumes
d. Whapsa-Moisture

Jeevamrita / Jeevamrutha / Bijamrita / Beejamrutha:

Jeevamrita is a fermented microbial culture which acts as a catalytic agent in the soil to proliferate the microbial diversity along with increase in the earthworm activity. The Beejamrita is used to protect the young plant roots from various soil and seed borne diseases through treatments of seeds, seedlings or any plant material. The composition of beejamrita is similar to that of jeevamrita.

Acchadana-Mulching: Acchadana is covering of the soil with different types of mulching materials which include.

A. Soil mulch: In this practice the top soil layer is protected during the cultivation by the tilling operations. Soil mulching is promoting through reduced/zero/no tillage practices. It improves soil water retention and aeration during the cultivation.

B. Straw mulch: Dried biomass of previous crops or any dead materials of plants and crops is used as straw mulch which helps in moisture protection along with prevention of emergence of weed plants during the cropping season.

Intercropping of Legumes (Symbiotic Intercrops and Mixed Crops) Legume crops play a crucial role in biological nitrogen fixation along with providing the extra yield as an intercrop. Also, the biomass of legume crops has low C:N ratio as compared to cereals and other crops which provide a large amount of easily decomposable organic matter along with supply of all essential nutrients during the cropping season. The legumes also play a role as live mulch. Intercropping includes the combination of dicots (legumes) and monocots (cereals).

Whapasa-Moisture: When both the air and water molecules are present in the soil, the condition is known as whapasa.

Nutrient Supply in Natural Farming through Organic Concoctions:

Jeevamrit / Jeevamrutha: Jeevamrit is a traditional fermented liquid organic concoction commonly used as soil microbial enhancer in natural farming. It is a rich source of Bacteria, fungi, actinomycetes and also contains other beneficial microorganisms. It is claimed that the application of jeevamrit stimulates crop growth and repels some of the insect-pests. It is prepared by using simple on-farm inputs like cow dung, urine, pulse flour, jaggery, water and microbial rich healthy soil. The sugars present in Jaggery acts as ready source of energy for growing microbes, while pulse flour (besan) acts as a nitrogen source in the formulation. Cow dung and urine provide nitrogen and other essential nutrients for growing microorganisms.

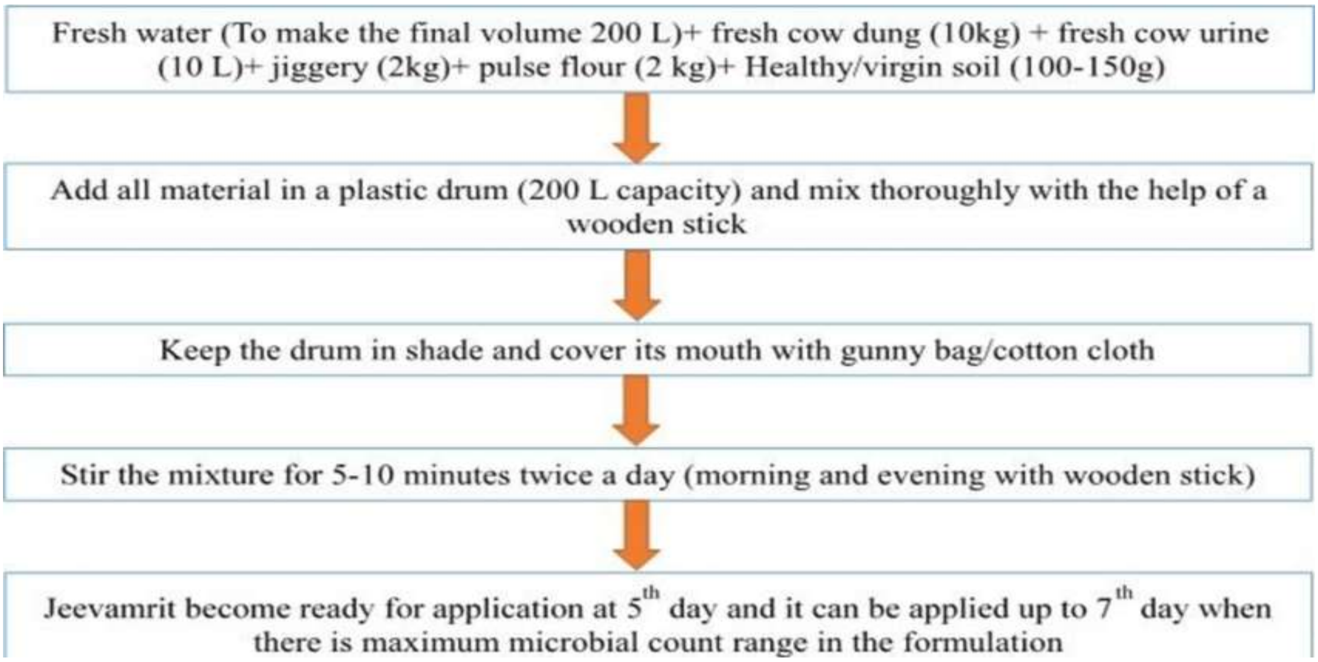

Fig. - Flow Diagram of Jeevamrit Preparation

Soil, Cow urine and dung provide the culture of beneficial microbes in the jeevamrit. During last few years, there has been an increasing interest on jeevamrit and other liquid organic formulations for use in organic and natural farming. The scientific characterization and validation of jeevamrit is under progress **(Kumar et al., 2021).**

Benefits of Jeevamrit Application: Jeevamrit is rich source of beneficial microbes. Its application in the soil helps in solubilizing/mineralizing the nutrients present in the soil/organic manures and thus, soil is able to provide the nutrients as per the needs of our crop.

In organic farming, application of organic manures in the soil must be supplemented with some microbial consortia or nutrient solubilizes/mineralizers which converts unavailable/fixed nutrients into available form and thus, increases the nutrient supplying capacity of soil. The unfavourable odour of jeevamrit acts as repellent to some of the insect-pests of crops.

Hence, Jeevamrit is the main concoctions in Zero-budget natural farming (now Subhash Palekar Natural

Farming); applied to enrich soil microbes with objectives of nutrient management. It is also claimed that, on-farm preparation of this organic formulation with cheaper ingredients helps to reduce the cost of cultivation and thus, decreases the market dependency of farmers (Aulakh et al., 2013).

Preparation of Jeevamrit: Jeevamrit is prepared by using simple on-farm inputs like cow dung, cow urine, pulse flour, jaggery, healthy soil and water. The water, cow urine and dung should be fresh and pulse flour and jaggery may be of low quality and cheaper to reduce the cost of production.

The soil should be either virgin or forest soil or from own organic farm where crop/vegetation health is best.

The preparation protocol of Jeevamrit is given with the flow diagram as below:

Application of Jeevamrit:

A. With irrigation water: Apply jeevamrit @500 lit /ha with irrigation water once or twice in a month as per the availability and needs. One can install jeevamrit drum/tanks with proper dropping and flow regulation arrangements over the irrigation channel near the tube well/source of water for automation of its application.

B. As foliar spray: Spray jeevamrit @5% during initial stage of crops (up to 25 days after sowing). Thereafter, 10% foliar application is suggested at every 20-25 days' interval. Depending upon the duration of crops, three to six applications may be required.

Foliar application of jeevamrit can be done with other liquid organic inputs/ nutrient sources.

C. As basal application in fruit crops: In adult fruit trees, application of 2-5 lit. of Jeevamrit is suggested in the basin around tree trunk once in a month.

Conclusion:

In the recent past, with the adverse impacts of intensive agriculture, natural farming has gained popularity among the farmers. Use of fermented organic concoctions in place of synthetic fertilizers and other agro-chemicals under natural farming contain live microorganisms to feed both the soil and plants. Along with this use of organic concoctions also promotes proliferation of earthworms and diversified soil microorganisms which further helps in maintaining long-term soil fertility.

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SURVIVAL BY PRETENDING: INSECT - SPIDER MIMICRY

Introduction

Mimicry is a survival adaptation of wherein one organism (mimic), mimics the appearance of other organisms (model) through colour patterns, body shape and behaviour. This strategy confers the organism with protection from predation through deception and facilitates access to resources. **Batesian mimicry** occurs when the mimic imitates an unpalatable model species. **Mullerian mimicry** occurs when both the mimic and the model are unpalatable, resulting in mutual avoidance by predators. **Wasmannian** mimicry occurs when the mimic resembles a host (model) in order to live within the same nest or structure.

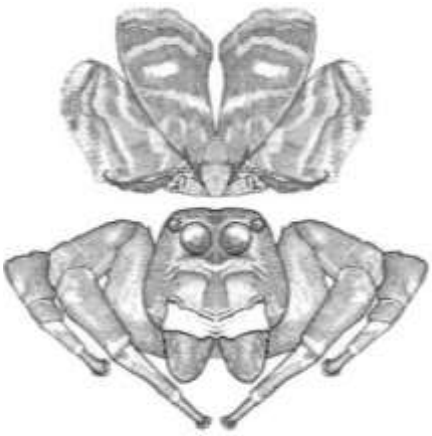
Case 1: Insects mimicking spiders

- **Metalmark Moth & Jumping Spider**

Model: *Phiale formosa* (Jumping spider, Family: Salticidae)

Mimic: *Brenthia hexaselena* (Metalmark moth, Family: Choreutidae)

This is an example of predator mimicry, in which the metalmark moths belonging the genus *Brenthia* mimic jumping spiders, one of their predators in order to escape them. Jumping spiders are visual predators. They distinguish the preys by their shape, symmetry, size, and style of motion. Jumping spiders also perform a behavourial display of a male raising and waving his forelegs at an intruder. *Brenthia* moths mimics this display where both males and females adopt a stance with their hindwings fanned outwards and brought forward, perpendicular to the forewings, the forewings are raised and held above the body at approximately a 45◦ angle. In this arrangement, the alternating colours of white and black on the hindwings resemble the spiders' legs. It also imitates the short and jerky movements characteristic of a jumping spider (Rota and Wagner, 2006)



- **Wattle Hopper & Jumping Spider**

Model: *Zenodorus orbiculatus* (Jumping spider, Family: Salticidae)

Mimic: *Gelastopsis insignis* (Spider-face wattle hopper, Family: Eurybrachyidae)

In this case, the mimic and model are be found on the same host tree stems. In order to deter the predator, the spider-face wattle hopper has evolved patterned wings and/or body parts with eyespots and markings that resemble the cephalothorax and legs of a jumping spider.

Case 2: Spiders mimicking insects

In this type, the mimicry works in reverse, as spiders mimic insects in order to get close to their prey or gain shelter in the nests of social insects like ants or to escape predation.

- **Ladybird mimic spider**

Model: *Coelophora inaequalis* (Common Australian ladybird, Family: Coccinellidae)

Mimic: *Paraplectana tsushimensis* (Ladybird mimic spider, Family: Araneidae)

These spiders have bright red or orange bodies with black spots. They also have a rounded appearance mimicking that of a ladybird. Ladybirds are distasteful to predators due to toxic alkaloids and bright warning coloration. The ladybird mimic spider benefits by mimicking the ladybird, gaining survival advantage by resembling an unpalatable insect, without being unpalatable itself. This is an example Batesian mimicry.

- **Weevil-Mimic Jumping Spider**

Model: *Trigonopterus laetus* (Black weevil, Family: Curculionidae)

Mimic: *Coccorchestes ferreus* (Jumping spider, Family: Salticidae)

Weevils are heavily sclerotized and not easy prey for many predators. The jumping spider benefits by disguising itself as a hard-shelled beetle, avoiding attacks. Weevils are known for their distinct elongated snouts, or rostrums. *Coccorchestes* mimic this by holding their short, central-facing mouthparts together, creating the illusion of a snout. To appear as a three-segmented insect rather than a two-segmented arachnid, they have a noticeable constriction between their cephalothorax and abdomen. They even mimic the dimpled texture found on the thoracic exoskeleton of their weevil models (Allan, 2022)

- **Ant-Mimic Jumping Spiders**

Ant mimicry by spiders, known as **myrmecomorphy**, is a widespread and highly evolved form of deception within the arthropod world. Hundreds of spider species across at least 13 families use this strategy to resemble ants, allowing them to gain protection from predators and, in some cases, to hunt other ants.

Model: *Oecophylla smaragdina* (Red weaver ant, Family: Formicidae)

Mimic: *Myrmaplata plataleoides* (Ant-mimic jumping spider, Family: Salticidae)

Model: *Crematogaster sp.* (Acrobat ants, Family: Formicidae)

Mimic: *Myrmaplata melanotarsa* (Dark-footed ant-spider, Family: Salticidae)

The body of *M. plataleoides* resembles that of an ant, possessing three distinct body segments and six legs. The constrictions on the cephalothorax and abdomen creates an illusion of having a distinct segment, complete with a long and slender waist of the ant. The large compound eyes of the weaver ant are mimicked by two black patches on the head. The spider raises the anterior pair of legs up and waves them in the air like antennae to complete the disguise.

This example works as a form of Batesian mimicry as well as Wasmannian mimicry where spiders are capable of invading ant colonies by mimicking the ants' pheromones. Upon gaining entry, they can prey upon ant larvae or their food resources. These species also take advantage of the fear that certain jumping spider species have towards ants, as ants are known to fiercely protect themselves. It has been observed that spiders from certain genera will retreat, abandoning their eggs, when confronted by groups of ants. *M. melanotarsa* consumes the eggs of these spiders.

Conclusion

These examples highlight the complex diversity of mimicry among arthropod classes and the deep evolutionary race between predators and prey, driving such adaptations.

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APPLICATION OF BIOMIMICRY IN MILITARY TEXTILES

ABSTRACT

Nature has created excellent technologies, serving as a primary mentor to humans in creativity and technology development. Fibres, a building block found in natural structures like wood, bamboo, bone, and muscle, have been used for spinning and weaving since time immemorial. Nature has also demonstrated sophisticated technologies for developing technical textiles, such as functional surfaces, camouflage, structural colour, thermal insulation, and dry-adhesion. Biomimicry can inspire innovative textile development.Bio-inspired materials are advancing next-generation military applications by emulating natural systems to create lightweight, durable, and multifunctional solutions. This overview highlights recent progress in bio-inspired materials, including their applications in armour systems, stealth technologies, adaptable structures, and energy-efficient gadgets. Significant developments include materials derived from nacre's resilience, biological tissues' self-repairing properties, and cephalopods' concealment strategies. Challenges like scalability, cost-effectiveness, and material dependability under harsh conditions are also addressed. This study explores the potential of bio-inspired materials to transform the defence sector and meet contemporary conflict requirements through case studies and upcoming trends.Biological mimicry and camouflage have three main themes: concealment, deception, and imitation. These concepts have similar analogs in the military, but they've received little attention. This paper applies these concepts to the military. Concealment, or camouflage, has a long history and is expected to become even more advanced in the future. Military deception involves using fakes and dummies to trick enemies. Imitation is examined from three perspectives: replacing military personnel with animals, exploring bioengineering, and using Artificial Intelligence to create robots, swarms, and avatars.The goal is to create a "living" textile system that actively enhances a soldier's survivability and operational effectiveness.

INTRODUCTION

Biomimicry refers to the design and production of materials, structures, and systems inspired by nature. In military textiles, biomimicry enables innovations such as enhanced camouflage, durability, and thermal regulation. Natural organisms like sharks, spiders, and chameleons provide models for stealth, strength, and adaptive coloration.

Aristotle famously asserted, "In all things of nature, there is something of the marvellous." This profound statement has profoundly impacted the art, fashion, and design industries for centuries. Nature's aesthetic appeal extends beyond mere visual beauty; it is meticulously crafted with specific functionality and a purposeful design. The world we inhabit is a dynamic entity that continually presents novel concepts and ideas. Biomimicry, derived from the Greek words for 'life 'and 'imitation, 'emulates nature's processes and functions to develop innovative technological advancements. Over 3.8 billion years of evolutionary history have shaped nature into a vast repository of design strategies that enable organisms to adapt and flourish in challenging environments. Bio-inspired materials science draws upon these evolutionary insights to create synthetic materials that mimic biological forms, structures, and functions. This approach, known as biomimetics, is increasingly influencing contemporary engineering, particularly in the defence and aerospace sectors.

Traditional materials encounter limitations in defence applications due to their inadequate performance under high stress, extreme temperatures, and dynamic environments. Consequently, the demand for multifunctional, lightweight, and adaptable materials has surged. Biomimicry, the imitation of nature's processes, has a long history, with the Chinese attempting to create artificial silk over 3,000 years ago, inspired by silkworms.

CONTENT

In above collage of biomimicry-inspired military textiles. It blends natural inspirations like shark skin, spider silk, lotus leaves, chameleon skin, and armadillo scales with futuristic military fabric designs in a striking visual composition: -

Biomimicry in military textiles draws directly from nature's genius to enhance performance, protection, and adaptability. Here's how each natural inspiration in your college translates into real-world military textile innovations:

Shark Skin → Water Resistance & Drag Reduction

- Inspiration: Shark skin is covered in dermal denticles—tiny, tooth-like scales that reduce drag and resist microbial growth.
- Application: Military wetsuits and swimwear mimic this texture to improve hydrodynamics and reduce bacterial buildup.

Spider Silk → Strength & Flexibility

- Inspiration: Spider silk is stronger than steel by weight and incredibly elastic.
- Application: Researchers are developing synthetic spider silk fibers for

lightweight, ultra-strong body armor and parachute cords.

Lotus Leaf → Self-Cleaning & Water Repellency

- Inspiration: Lotus leaves have micro- and nano-structures that repel water and dirt.
- Application: Lotus-effect fabrics are used in military uniforms and tents to stay clean and dry in harsh environments.

Chameleon Skin → Adaptive Camouflage

- Inspiration: Chameleons change color by manipulating nanocrystal in their skin.
- Application: Smart textiles with embedded sensors and pigments can shift color to match surroundings, aiding stealth operations.

Armadillo Scales → Flexible Armor

- Inspiration: Armadillos have overlapping bony plates that provide protection while allowing movement.
- Application: Segmented armor systems in military gear mimic this design for better mobility and impact resistance.

Why Biomimicry Matters in Military Textiles

- Efficiency: Nature-inspired designs often use fewer resources and offer multifunctionality.
- Survivability: Enhanced protection, stealth, and adaptability directly improve soldier safety and mission success.
- Innovation: Biomimicry pushes the boundaries of textile engineering into smart, responsive, and sustainable territory
- Camouflage: Dynamic patterns, modeled after cephalopod (like octopus and squid) skin, enable fabrics to change appearance for better concealment.
- Durability: High-strength fibers, inspired by spider silk, result in textiles that are both strong and lightweight.
- Thermal Regulation: Hollow fiber structures, mimicking polar bear fur, are used to improve insulation and temperature control in clothing.
- Smart Fabrics: Responsive materials, modeled after plant movements, allow textiles to adapt to environmental changes or user needs.

PRINCIPLES

The fundamental characteristics, mechanisms, or processes observed in nature are abstracted into general design principles or strategies, formulated in non-biological terms. For instance, the lotus leaf's super hydrophobicity is translated into the principle of creating a rough, waxy microstructure on a surface to retain air and repel water and dirt.

Emulate Nature's Lessons (Engineering and Prototyping):

Engineers and material scientists employ abstract design principles to develop innovative solutions. This phase entails applying advanced techniques and materials to replicate the natural property. Techniques include nanotechnology and advanced polymers to create microscopic textures or novel fiber compositions that mimic natural structures, genetic engineering to produce materials such as synthetic spider silk proteins in large quantities, and specialized manufacturing techniques such as additive manufacturing (3D printing) or specific weaving/coating methods to integrate the desired functionality into the textile.

Integrate into Textile Engineering and Evaluate:

The developed material is subsequently integrated into the final military textile product using appropriate weaving, coating, or layering techniques. The final product undergoes rigorous testing to ensure it satisfies the initial criteria and constraints of the design challenge while also evaluating its sustainability and feasibility. Evaluation encompasses testing for durability, functionality (e.g., the longevity of color change or the fabric's resistance to washing), and performance in pertinent military scenarios.

DISCUSSION

1.Applications in Camouflage

- Dynamic Patterns: Inspired by cephalopods (like octopus and squid), military textiles are being developed with the ability to change their appearance in real time. These fabrics use materials that can shift color or pattern, mimicking the rapid adaptive camouflage of these sea creatures. This allows soldiers and equipment to blend seamlessly into different environments, greatly enhancing stealth and survivability.
- Chameleon Skin: The adaptive coloration of chameleons has led to research into textiles that can alter their color or brightness in response to environmental cues, further improving concealment.

2. Durability

- Spider Silk-Inspired Fibers: Spider silk is renowned for its exceptional tensile strength and flexibility. Military fabrics modeled after spider silk are both lightweight and extremely durable, offering protection without adding bulk. These fibers can be used in body armor, parachutes, and other gears where strength-to-weight ratio is critical.
- Self-Healing Materials: Some research is exploring self-healing properties found in nature (such as certain plant tissues) to create textiles that can repair minor damage automatically, extending the lifespan of military gear.

3. Thermal Regulation

- Polar Bear Fur: Polar bear fur consists of hollow fibers that trap air, providing excellent insulation. Military cold-weather gear mimics this structure to retain body heat in extreme conditions, improving comfort and reducing the risk of hypothermia.

- Stomata-Inspired Fabrics: Some smart textiles are inspired by the stomata (tiny pores) in plant leaves, allowing for moisture management and breathability. These fabrics can regulate temperature and wick away sweat, keeping soldiers dry and comfortable.

4. Smart Fabrics

- Responsive Materials: Drawing inspiration from plant movements (such as the opening and closing of flowers), smart military textiles can adapt to environmental changes. For example, they may become more breathable in hot conditions or more insulating in cold weather.

- Embedded Sensors: Future trends include integrating sensors into fabrics, enabling real-time monitoring of soldier health, environmental hazards, or even camouflage effectiveness.

5. Hydrophobic and Self-Cleaning Surfaces

- Lotus Effect: Inspired by the lotus leaf, which repels water and dirt due to its micro-structured surface, military textiles can be engineered to be self-cleaning and water-resistant. This reduces maintenance and enhances performance in wet or muddy environments.

6. Drag Reduction

- Shark Skin: The microstructure surface of shark skin reduces drag in water. This principle is applied to military wetsuits and aquatic gear, allowing for faster and quieter movement underwater.

Significance and Future Directions

Biomimicry in military textiles leads to gear that is more adaptive, resilient, and efficient. These innovations not only enhance soldier protection and operational effectiveness but also promote sustainability by reducing the need for frequent replacements and minimizing environmental impact. Ongoing research is focused on making these advanced materials more affordable and scalable for widespread military use.

Advantages

- Improved Performance: Biomimetic textiles leverage nature-inspired designs to enhance key properties such as stealth, durability, thermal regulation, and adaptability. For example, shark skin-inspired surfaces reduce drag, spider silk-inspired fibers increase strength, and chameleon skin-inspired materials enable dynamic camouflage. These innovations make military gear more effective in diverse and demanding environments.

- Sustainability: By mimicking efficient natural systems, these textiles often require fewer resources and can be more environmentally friendly. The potential for self-healing and self-cleaning fabrics also reduce waste and the need for frequent replacements.

Challenges

- High Production Costs: Advanced biomimetic materials often rely on sophisticated manufacturing processes, such as nanotechnology or specialized polymers, which can be expensive to scale.
- Scalability: Translating laboratory breakthroughs into mass-produced, field-ready textiles remains a significant hurdle. Ensuring consistent quality and performance at scale is a key challenge for widespread adoption.

Future Trends

- Smart Fabrics: The next generation of military textiles will likely feature embedded sensors and adaptive capabilities. These smart fabrics could monitor soldier health, detect environmental hazards, or automatically adjust insulation and camouflage in real time.
- Enhanced Soldier Safety and Efficiency: By integrating adaptive and responsive technologies, future biomimetic textiles aim to further improve protection, comfort, and operational effectiveness for military personnel.

Current Research Examples in Biomimetic Military Textiles

1. Adaptive Camouflage Inspired by Cephalopods and Chameleons

- Cephalopod-Inspired Camouflage: Researchers are developing fabrics that mimic the dynamic color-changing abilities of squid and octopus's skin. These textiles use electrochromic cells and photonic crystals to change color and pattern in real time, providing advanced concealment across visible and infrared spectrums. This technology is being explored for uniforms and equipment that can adapt to different environments on demand.
- Artificial Chameleon Technology: Bionic materials are being engineered to replicate the rapid color and brightness changes seen in chameleons, using advanced sensors and actuators for real-time environmental adaptation.

2. Smart and Intelligent Textiles

- Fiber-Based Computing: MIT researchers have created fiber computers that can be woven into garments, enabling real-time health monitoring, activity tracking, and environmental sensing. These smart textiles are being tested by the U.S. military in extreme conditions to monitor physiological responses and prevent injuries.
- Integrated Sensors: Modern military fabrics are being designed with embedded sensors for health monitoring, communication, and detection of chemical or biological threats. These smart textiles can autonomously process and transmit data, enhancing soldier safety and operational effectiveness.

3. Bio-Based and Sustainable Materials

- Natural Fiber Composites for Ballistic Armor: Researchers are investigating natural fiber-reinforced polymer composites (NFRPCs) using materials like jute, flax, and hemp as lightweight, sustainable alternatives to traditional synthetic fibers in ballistic protection. These composites offer environmental benefits and are being optimized for use in body armor and vehicle protection.
- Bio-Based Camouflage Materials: The U.S. Army is funding research into bio-based fabrics for camouflage covers and seat materials, aiming to improve sustainability, reduce costs, and meet domestic manufacturing requirements.

4. Functional Coatings and Self-Cleaning Surfaces

- Lotus Effect and Self-Cleaning Textiles: Inspired by the lotus leaf, new textile coatings are being developed to provide water repellency and self-cleaning properties. These coatings use micro- and nano-structured surfaces to repel water and dirt, reducing maintenance and improving performance in harsh environments.
- Multifunctional Coatings: Recent advances include coatings that impart flame resistance, antimicrobial properties, and self-cleaning abilities using bioactive materials and nanoparticles. These multifunctional textiles are designed for enhanced protection and sustainability in military applications.

5. Living and Responsive Textiles

- Living Textiles: Interdisciplinary research is exploring textiles that incorporate living microorganisms or bio-hybrid systems, enabling fabrics to respond to environmental stimuli, self-repair, or even grow new material. This field is at the intersection of biotechnology and textile engineering, with potential for radically reducing environmental impact.

6. Advanced Camouflage and Stealth Technologies

- Spectral Reflection Camouflage: Research is ongoing into bionic camouflage materials that simulate the spectral reflection characteristics of plants, making military textiles less detectable by hyperspectral imaging and remote sensing technologies.
- Infrared and Radar-Absorbent Fabrics: New coatings and fiber blends are being engineered to absorb or scatter infrared and radar signals, reducing the visibility of soldiers and equipment to modern surveillance systems.

Key Takeaways

- The field is rapidly advancing, with a strong focus on adaptive, sustainble, and multifunctional textiles.
- Collaboration between defense agencies, universities, and industry is driving innovation, with real-world testing underway for several technologies.

CONCLUSION

Biomimicry provides a transformative approach to military textile design. By leveraging nature's solutions, researchers can create fabrics that meet the demanding requirements of modern defence systems while promoting innovation and sustainability.

This conclusion emphasizes that biomimicry is not just a source of inspiration but a powerful strategy for advancing military textiles. Researchers use nature's proven solutions to create fabrics that are:

- Highly functional (e.g., enhanced camouflage, durability, thermal regulation)
- Innovative (incorporating smart and adaptive features)
- Sustainable (reducing resource use and environmental impact)

Ultimately, biomimicry helps bridge the gap between high-performance requirements and the need for sustainable, forward-thinking solutions in defence applications.

The integration of smart sensors, bio-based materials, and advanced coatings is set to redefine the future of military textiles.

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VIABLE PLAN FOR AVAILABILITY OF FRESH AND STORED FODDER THROUGHOUT THE YEAR

Introduction

Livestock sector plays an important role in the national economy and in the socio-economic development of the country. But productivity of our animals is 20-60%, which is lower than the global average. The low productivity of animals is affected by several factors such as limited awareness of fodder cultivation, and Insufficient and imbalanced feeding with low-grade feed materials, and various physiological disorders and diseases owing to lack of proper nutrition. Among these, the deficiency of quality feed and fodder is one of the most important factors contributes towards lower productivity. In India limited land (8.6 Mha) is available for fodder cultivation and there is a net deficiency of both green as well as dry fodder by about 30.65% and 11.85%, respectively in Vision 2050. Looking at the vast gap between the demand and supply, there is an urgent need for formulation of strategies for the continuous inflow of feed materials.

Table:1 Demand and supply of fodder in India (in million tonnes) over the years.

Year	Demand		Supply		Deficit		% Deficit	
	Green	Dry	Green	Dry	Green	Dry	Green	Dry
2010	816.8	508.9	525.5	453.2	291.3	55.72	35.66	10.95
2020	851.3	530.5	590.4	467.6	260.9	62.85	30.65	11.85
2030	911.6	568.1	687.4	500.0	224.4	68.07	24.59	11.98
2040	954.8	594.9	761.7	524.4	193.0	70.57	20.22	11.86
2050	1012.7	631.0	826.0	547.7	186.6	83.27	18.43	13.20

IGFRI Vision: 2050

Strategies of Year-Round Fodder Production

To ensure continuous availability of fodder during both flush and lean seasons, several innovative technologies and management practices may be adopted. The important strategies include:

1) Innovative Technologies for quality seed production
2) Production strategies of fodder crops
3) Introduce agroforestry system like silvi/horti pasture models
4) Hi-tech farming
5) Innovative techniques in fodder preservation
6) Establishment of community fodder banks and Complete feed block technology

Thus, the need of the hour is not only to enhance the fodder production, but also to make the fodder accessible throughout the year. In hi-tech farming a novel approach called hydroponic fodder cultivation could have been alternative technology for fresh fodder. Farmers can plan properly to get round the year fodder using various innovative technologies.

1. Innovative Technologies for quality seed production

In India, only 25-30% of the required quantity of quality seeds is available for cultivated fodder crops, while the availability of seed for range grasses and legumes remains below 10%. So, there is a need to develop superior, high-yielding varieties and adopt advanced technologies for large-scale seed multiplication. To enhance fodder seed availability, a combination of genetic improvement and modern seed production technologies is essential. Key strategies for increased seed production include:

2. Production strategies of fodder crops

Ensuring year-round fodder availability requires a system approach, where suitable crops, improved varieties and appropriate production technologies are planned according to local conditions. Farmers should select crops that fit well into existing farming systems and follow cropping sequences that provide continuous green fodder during lean periods.

Seasonal Crop Sequence for Year-Round Fodder Production

A basic model showing how different fodder crops can be grown in sequence within the same year:

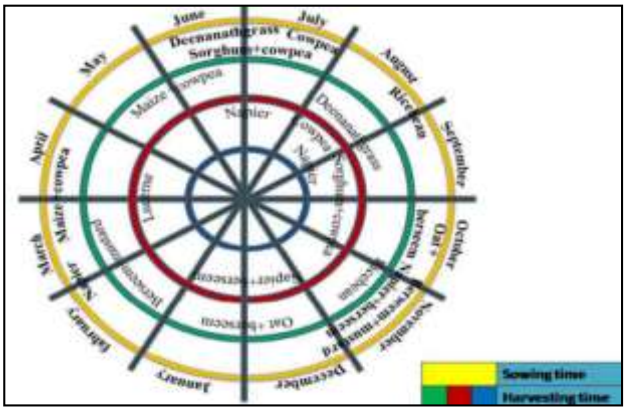

Fig 1: Year-round fodder production model (Kumar *et al*., 2022)

Different cropping systems for year-round fodder production:

A major challenge in Indian agriculture is ensuring the continuous supply of green fodder, especially during lean seasons. The traditional rice-wheat rotation provides limited fodder and gradually reduces soil health due to repeated monocropping. To overcome this, researchers recommend introducing fodder crops into the rice-based system to improve productivity and supply nutritious forage round the year.

Sequential cropping

S. No.	Crop sequence	Green fodder yield (t/ha/year)
1	Napier x Bajra hybrid + Cowpea - Berseem	260
2	Maize + Cowpea MP Chari + Cowpea Berseem + Japanese rape	197
3	MP Chari + Cowpea Berseem + Japanese rape	184
4	Cowpea MP Chari + Cowpea Berseem + Japanese rape	176
5	Napier x Bajra hybrid + Cowpea Berseem Cowpea	255

Source: Kumar *et al*., (2022)

Diversified Fodder Production System

A reliable year-round supply of green fodder is vital for improving livestock productivity. To support farmers in different rainfall zones, the Indian Grassland and Fodder Research Institute (IGFRI), Jhansi has developed practical models that combine grasses, legumes and seasonal crops for irrigated and rainfed conditions. Farmers can also grow grasses like BN hybrid, TSH, guinea, anjan and crops like cactus, subabul and moringa on field borders and bunds without affecting main crops.

3. Agroforestry

Agroforestry integrates fodder trees with grasses or legumes to supply forage throughout the year while improving soil health and biodiversity. Models such as silvi-pasture and horti-pasture systems produce more forage than open grasslands by combining grasses and legumes with trees such as Aonla, Guava, Subabul or forest species. These systems are ideal for degraded lands and help meet the demand for fodder, fuel wood and fruit.

4. **Hi-tech farming**

Hi-tech farming uses modern techniques to produce high-quality fodder efficiently, even in limited space or under challenging conditions. Although it requires investment in equipment, training, and maintenance, it ensures continuous availability of nutritious feed for livestock. Vertical farming grows fodder in stacked layers, allowing year-round production without heavy reliance on fertile soil, abundant water, or skilled labour, while maximizing space and family labour use. In rooftop or terrace farming, high-density fodder grass is cultivated in grow bags with drip irrigation, enabling fast growth up to 6 - 8 feet in two months, while reducing feed costs by replacing expensive concentrates with fresh green fodder. Hydroponic fodder cultivation involves production of sprouting fodder without soil using nutrient-rich water and sunlight, producing highly digestible and palatable feed that improves milk yield, animal health, and reproduction. Together, these hi-tech methods help farmers overcome land and labour limitations, reduce costs, and maintain a reliable, high-quality supply of green fodder throughout the year.

5. Innovative techniques in fodder preservation

To maintain year-round availability of nutritious fodder, several preservation techniques are used:

Silage: Silage is green fodder stored airtight to retain moisture and nutrients. During ensiling, lactic acid forms, lowering pH and preventing spoilage. High-quality silage is yellow-green with a mild vinegar smell. Crops like maize, sorghum, bajra, oats, barley, and perennial grasses such as Hybrid Napier, Guinea, Para, Sudan, and Rhodes grass are ideal. The process involves harvesting at the right stage, chopping, compacting, and storing in silos or airtight containers. Proper silage has a pH of 3.5-4.2 with adequate lactic acid content.

Haymaking: Hay is dried fodder prepared by reducing moisture to 15-20%, which preserves protein and nutrients. Cereals are harvested at heading, legumes at flowering. Drying can be done in the field (field curing) or in sheds (artificial curing), which reduces nutrient losses and allows harvesting regardless of weather.

Haylage and Balage: Haylage is partially dried fodder (40-60% moisture) stored airtight for fermentation. It can be baled and wrapped to maintain nutrients. Balage (round-bale silage) uses higher moisture fodder, sealed in plastic for anaerobic fermentation, providing long-term storage with minimal wastage.

6. Community Fodder Management and Complete Feed Blocks

Innovative approaches like community fodder banks and complete feed blocks (CFB) help farmers maintain a steady supply of nutritious fodder and improve livestock productivity. In a community fodder bank, farmers collectively cultivate a variety of fodder crops on wastelands or non-arable lands. These banks store surplus fodder, provide high-quality feed during shortages, and make use of crop residues and other unconventional materials, benefiting both soil health and animal nutrition. Complete feed blocks are created by compressing a mixture of forage, concentrates, and supplements such as molasses, minerals, and salt into solid blocks. This ensures animals receive a balanced diet, improves fibre digestion, and prevents selective feeding. The technology is simple, easy to transport, conserves green fodder during surplus periods, and is well-suited for stall-fed animals. Together, these methods support efficient fodder management, better nutrition, and sustainable livestock farming.

7. Use of enriched crop residues

Crop residues are the fibrous leftovers from harvested crops, such as cereal straws, which are often underutilized. These residues are low in nutrients, hard to digest, and may contain anti-nutritional elements like silica, oxalates, or fungal toxins, limiting their value as livestock feed. To make them more nutritious and palatable, enrichment techniques are applied. One approach is dehydration and pelletizing, where chopped or ground residues are compressed into cubes or pellets for easy storage and feeding. For example, feed pellets can be enriched by adding dried Azolla, berseem, or moringa leaves, improving protein content and overall nutritional value. Machines like the Power Operated Feed Pelleting Machine developed by IGFRI which produce the value-added feed products efficiently. These enriched residues provide a reliable, high-quality feed source for animals, especially during fodder shortages.

Conclusion

To meet the current level of livestock production, the deficit of fodder has to be met either by increasing productivity, utilizing untapped feed resources or increasing land area.

Adopting a systemic, scientific and long-term approach for fodder crops can boost the availability and supply of quality fodder seeds to farmers. Proper conservation of green fodder, value addition of crop residues, establishment of fodder banks and improvement of pastures, and grasslands need to be considered for profitable dairy farming. These fodder production techniques enable farmers to provide nutritious, high-quality feed for their animals, while round-the-year fodder availability supports sustained milk production and helps farmers achieve higher economic returns.

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PRECISION PEST MONITORING THROUGH IMAGE AND ACOUSTIC SENSING TECHNOLOGIES

Abstract

Post-harvest insect infestation remains a major challenge in agricultural storage, contributing to nearly 20–40% of grain losses worldwide. Traditional monitoring methods often fail to detect early-stage infestations, especially when destructive pests remain hidden inside kernels. This article explores how modern digital technologies specifically acoustic sensors and image-based detection systems are transforming pest surveillance in warehouses. Acoustic sensors identify insects by capturing the sounds produced during feeding and movement within grains, while image sensors use advanced models like YOLO to recognize insects visible on grain surfaces or storage structures. By integrating machine learning, real-time alerts, and automated monitoring systems, these tools enable early detection, reduce labor needs, and enhance decision-making. Together, these innovations mark a shift toward smarter, more efficient storage systems that protect grain quality and strengthen food security.

Keywords: Acoustic pest detection, Image-based insect monitoring, Post-harvest grain protection, Machine learning in pest surveillance, Precision pest monitoring, Smart warehouse technologies.

Introduction

Storage is a critical part of agriculture. After months of effort in the field, farmers must safely store the harvest so that it remains available for consumption, processing, and market supply. However, post-harvest losses especially those caused by insects, pose a major challenge. Biotic threats such as insects, mites, bacteria, fungi, rodents, and birds, along with abiotic stresses like temperature, humidity, moisture, and oxygen levels, can severely affect stored produce. Among these, **insects contribute nearly 20–40% of post-harvest losses,** making effective monitoring essential. Traditional surveillance methods, although useful, are labour-intensive, time-consuming, and often unable to detect early-stage infestations. Today, technology offers smarter solutions. By integrating **acoustic sensors** and **image-based systems,** warehouses can move from manual inspection to automated, real-time pest monitoring. These innovations help detect insects early, improve decision-making, and reduce losses.

Acoustic Sensors in Pest Detection

Some of the most destructive insects, especially those that attack stored grains spend their early life stages hidden inside kernels. These immature forms cannot be seen with the naked eye and are difficult to detect using conventional methods. Acoustic technology provides a breakthrough here by **listening** to insects rather than looking for them. As insects move, feed, or chew within grains, they produce characteristic sound patterns. Acoustic detection is especially valuable because it can identify insect presence even before visible damage occurs which is a major advantage for stored-grain protection.

How Acoustic Detection Works

1. Signal Pre-Processing

Raw sound recordings from the grain are first filtered to remove background noise. Band-pass filtering isolates the specific frequency range associated with insect activity. Low-energy, irrelevant signals are discarded, leaving only meaningful acoustic data.

2. Feature Extraction and Pattern Recognition

The system analyzes the acoustic patterns tone duration, pulse bursts, temporal patterns, and spectral signatures. Advanced methods like wavelet analysis, MFCCs (Mel-Frequency Cepstral Coefficients), LPCCs, and independent component analysis help distinguish insect sounds from environmental noise.

3. Machine Learning and Classification

Machine learning models such as Artificial Neural Networks, Gaussian Mixture Models, and K-Nearest Neighbors classify the detected sounds. These algorithms learn to differentiate insect-generated acoustic bursts from background disturbances.

4. Physical Factors Considered

Temperature, grain moisture, and sound attenuation influence detection accuracy. Modern systems integrate these parameters to improve reliability.

5. Real-Time Detection Systems

Innovative tools like the Post-harvest Detection System (PDS) and TreeVibes use microphones and accelerometers to continuously monitor grain bins. They estimate insect

(a) (b)

population levels and send alerts when activity crosses a threshold.

Image Sensors in Pest Detection

While acoustic sensors detect hidden larvae, image-based systems excel at identifying **visible insect activity** on the surface of grains or storage structures.

1. Data Acquisition and Simulation Setup

The process begins by capturing images or videos under controlled storage-like conditions. Cameras or mobile robotic devices scan grain surfaces, bag stacks, or warehouse floors, collecting thousands of images that represent real-world scenarios.

2. Data Processing and Annotation

The raw images are cleaned, noise is removed, and frames are standardized. Specialists annotate images by marking insect locations. These annotations teach the system what insects look like in different positions, lighting conditions, and backgrounds.

3. Dataset Division

The prepared dataset is divided into:

- **Training set** – to teach the model
- **Validation set** – to fine-tune model parameters
- **Testing set** – to evaluate performance

This ensures that the final model performs well on new, unseen images.

4. Model Development using Transfer Learning

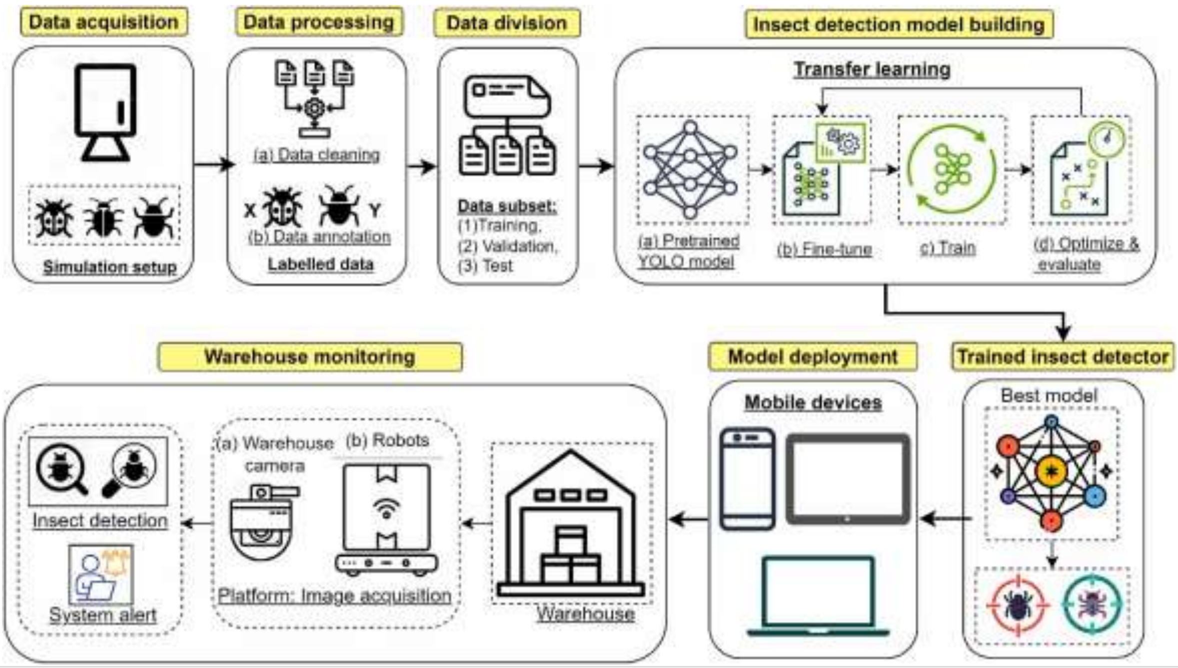
One of the most efficient approaches is **transfer learning** using pre-trained detection models like **YOLO (You Only Look Once).** YOLO is known for its high-speed, high-accuracy object detection.

The steps include:

- Importing the pre-trained YOLO model
- Fine-tuning it with insect images
- Training and optimizing the network
- Evaluating accuracy, precision, and detection speed

After several training cycles, the best-performing model is selected for deployment.

5. Real Time Detection and Alerts



The trained model is integrated into mobile devices or computer systems. Cameras installed in warehouses continuously capture images. Whenever the system identifies an insect, it highlights the pest on the screen and sends an immediate alert.

Some warehouses use **autonomous robots** equipped with cameras to monitor large spaces. These robots transmit images to the detection system, which analyzes them and provides instant notifications, enabling timely intervention.

Why this integration of both technologies?

Combining acoustic and image-sensor technologies creates a comprehensive early-warning system for pest surveillance:

- Acoustic sensors detect hidden larvae inside grains.
- Image sensors identify active insects on surfaces.
- Machine learning models reduce human error.
- Real-time alerts help prevent large-scale infestations.
- Automated monitoring reduces labour and improves efficiency.

Such digital tools move storage systems toward smart warehouses, improving grain quality, reducing losses, and enhancing food security.

Conclusion

Modern pest management is no longer limited to chemical treatments or visual inspections. Technologies like **acoustic and image sensors** represent a powerful shift toward intelligent, proactive storage management. These systems detect insect activity early, provide accurate insights, and enable timely interventions, all of which help safeguard stored grains and support sustainable agriculture.

As agriculture continues to integrate digital tools, the future points toward fully automated warehouses where pests are detected and managed long before they become a threat.

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STERILE INSECT TECHNIQUE

Introduction:

The idea of sterile insect technique fall under genetic control of insects, that alters the ability of the target pest to reproduce or insert some deleterious character into the pest population. The genetic control is a form of biological control of pest population which exploits the insects mateseeking expertise and introduces genetic abnormalities into eggs of wild population.

The sterile insect technique was first introduced by E.F.Knipling in 1937 in the laboratory of Texas, USA, while studying the biology of the screwworm fly, *Cochliomyia hominivora*(Coquerel), he observed that the female fly mated only once, and then he argued that if the males of this fly will be sterilised then the females would fail to produce viable eggs thus the insect population can be controlled. E.F.Knipling contrived a new approach to control the insect population by disrupting their natural reproduction by physical or chemical means. This concept was then used for screwworm fly in 1950s and eventually called as **Sterile insect technique (SIT)** or **Sterile insect release method (SIRM)**. Studies on insect reproduction from the early 1900s till now have shown that the insects treated with certain mutagenic chemicals (chemosterilants) or x- rays, gamma rays(ionising radiation)they are unable to reproduce a normal number of offsprings. These treated insects which may become fully or partially sterile are released in large number in the field and it is expected that they will mate with the natural population thus disrupting reproduction.

Concept of Knipling's Technique:

The concept of E.F.Knipling's technique involves sterile male technique and sterile insect technique.

Sterile male technique: In this method only the sterile males are released into the field, these males mate with wild females, but no eggs hatch because the males are sterile. When the ratio of sterile male is very high compared to fertile male more chance is that females will mate with sterile ones as a result, few offsprings are produced thus slowly the population reduces.

Sterile insect technique: This is also called as sterile insect release method where both male and female insects from the wild population are sterilised by chemicals or ionising radiations. Then these sterilised insects are released back to the field and they mate with the wild population but cannot produce offspring. The sterilised male and female of wild population will in turn, nullify the reproducing capacity of a fraction of fertile individuals in the population by competing with them thus this method combines both chemical and biological control method.

CHEMOSTERILANTS:

Chemosterilants are the chemical compounds used to control the insects causing economical damage by inhibiting the growth of gonads or by causing temporary or permanent sterility of both of the sexes (prevent copulation, production of viable eggs) or may inhibit development of progeny at any stage(egg, larva, pupa). These are grouped into alkylating agents and antimetabolites. The alkylating agents such as TEPA, METEPA, Apholate cause change in genetic material and chromosomal damage in reproductive cells of both the sexes. Antimetabolites such as amethopterin and aminopterin causes female sterility by preventing egg formation, hatching of egg, larval development.

Field trials:

Agricultural pest: Some experiments have been tried with lepidopteren insects like cabbage looper, *Trichoplusia ni* (Hubner);pink cotton bollworm, *Pectinophora gossypiella* etc. Some actual field trials have been conducted in California on Mexican fruit flies (with TEPA) and in Alabama on the cotton boll weevil (with apholate).

Public health pests: Housefly were first chemosterilized with TEPA mixed in food bait in Florida in 1962. Nine weeks treatment brought the insect population down. Testse flies were also chemosterilized in Zimbabwe and 98 per cent control was achieved but complete irradication is not possible due to reinvasion from the adjacent areas.

Scientific name	Common name	Stage	Sterilizing dose (rads)
Cochliomyia hominivorax (Coquerel)	Screwworm fly	5-days pupae 1-day adult	2500 5000-7000
Musca domstica Linnaeus	House fly	2-3 days pupae	3000
Drosophila melanogaster	Fruit fly	Adult males	11000-12000

Table : Estimated doses of gamma rays and x-rays for male sterilization

IONISING RADIATIONS:

The insects can be sterilised by exposing them to(alpha, beta, gamma) radiations, X-rays and neutrons out of these gamma radiation with ^{60}CO with its half-life of 6 years, is the most common method. The doses for radiation differ for different species eve for different stage of same insect species. High dose provides complete sterilisation i.e all the generation produced by the sterile insect will be sterile and a low dose provides partial sterilisation that may not continue after F_1 generation.

Consideration of SIRM

I. **Time and place of release**
   - The time and place of release should be such that it allows intermingling of the population.
   - Emergence of adult from released pupae should coincide with emergence of wild adults.

II. **Sex of the insect to be released**
   - The choice of sex depend on monogamous and polygamous nature of insect(If female is monogamous and male is polygamous then release of sterilised male is more effective).

III. **Basic requirements of SIRM**
   - **Rearing method**: Easy and efficient method to rear a number of insects in the lab should be there so that more insects than the natural population can be released.
   - **Reliable sterilization:** There must be proper method available to make the insects sterile such as chemicals or radiation.
   - This method should induce sterility should not impair sexual behaviour of the insect. The sterile insect should be able to successfully mate with the wild insects.
   - **Accurate population estimates**: correct estimates are needed so that the right number of sterile insects can be released.
   - **Proper distribution of released insects**: The released insect must be distributed so that they can compete with wild insects for mating.
   - The released insect should not cause damage to the crops, livestock and human.
   - Need to know the growth rate of the natural population accordingly we can decide how

many sterile insects to release and its frequency.

Some successful examples:

- Eradication of screwworm fly in island of Curacao. The males were sterilized by gamma radiation and were released @ 400 per square mile per week.
- Eradication of oriental fruit fly from the island of Tinian
- Eradication of melon fruit fly on the island of Rota
- Eradication of field cockchafer in Switzerland
- Eradication of oriental fruit fly and melon fruit fly from Taiwan and Japan respectively

Conclusion:

The potential of this method of control has yet to be fully exploited despite the fact that the theoretical knowledge have been with since long. This type of genectic control are highly species specific and hence do not cause any adverse effect on non target organisms. Its application does not pollute environment and is also safe for farmers also can be incorporated with other pest management strategies like chemical , cultural, mechanical etc.

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HIDDEN DEFICIENCY: UNMASKING INDIA'S VITAMIN D PROBLEM

Introduction

Vitamin D plays a crucial role in maintaining bone health, supporting immunity, and regulating several metabolic functions. India, being a tropical country, has ample sunlight throughout the year and also produces several foods that naturally contain or are fortified with vitamin D. Despite this, vitamin D deficiency remains a major public-health concern in India. This contradiction raises an important question: Why does deficiency persist even though India produces and consumes vitamin D-rich foods? The issue can be understood by examining lifestyle changes, dietary patterns, socio-cultural factors, and biological limitations.

1. Limited Sun Exposure Despite Abundant Sunlight

India receives strong sunlight, which should ideally support natural vitamin D synthesis in the skin. However, modern lifestyles have drastically reduced outdoor exposure. Urbanisation has led to people spending most of their time indoors - in offices, classrooms, and homes. Even when outdoors, many avoid direct sunlight due to fear of tanning, cultural preference for lighter skin, or high temperatures. Environmental pollution adds an extra barrier by blocking UVB rays necessary for vitamin D production. Thus, despite the availability of sunlight, its effective utilisation remains low.

2. Dietary Sources Are Limited and Often Insufficient

Although India produces vitamin D–rich foods like milk, mushrooms, eggs, and fish, the actual consumption levels are inadequate. Natural food sources of vitamin D are few and contain relatively small amounts. Many people, especially vegetarians, rely mainly on plant-based diets that naturally provide very little vitamin D. Fortified foods such as vitamin D milk or oil exist, but awareness and accessibility are limited. In rural regions, socioeconomic challenges further reduce dietary diversity, contributing to poor intake.

3. Poor Absorption Due to Nutritional Imbalances

Vitamin D absorption requires adequate levels of fat because it is a fat-soluble vitamin. However, widespread malnutrition, low-fat diets, and gastrointestinal issues such as malabsorption, intestinal infections, and chronic diseases reduce the ability of the body to absorb or utilise vitamin D efficiently.

Additionally, deficiencies in calcium and magnesium—minerals closely linked with vitamin D metabolism—further weaken vitamin D activity in the body.

4. Cultural Clothing Practices

Many individuals, especially women, wear clothing that covers most of the body for cultural, religious, or personal reasons. This limits skin exposure to UVB rays and reduces natural vitamin D synthesis. This is one reason why vitamin D deficiency is reported more frequently among women and children.

5. Skin Pigmentation and Biological Factors

Darker skin, which is common among the Indian population, contains more melanin. Melanin acts as a natural sunscreen and reduces the skin's ability to synthesise vitamin D. As a result, people with darker skin require longer sun exposure to produce the same amount of vitamin D as those with lighter skin.

6. Increasing Prevalence of Obesity

Vitamin D is stored in fat tissues. In overweight or obese individuals, vitamin D gets trapped in fat and becomes less available for the body to use. With rising obesity rates in India, this has become a significant factor contributing to widespread deficiency.

7. Lack of Awareness and Screening

A major reason for persistent deficiency is low awareness about vitamin D's importance and the symptoms of deficiency, which are often mild or nonspecific. Routine screening is uncommon, and many individuals discover a deficiency only after experiencing bone or muscular problems. Lack of health education, especially in rural areas, further worsens the problem.

8. Inadequate National Fortification Programs

Although India has started food fortification programs, they are not uniformly implemented. Fortified milk, oil, or flour is not available or affordable to everyone. Stronger fortification policies and better public distribution could significantly reduce deficiency, but progress has been slow.

Conclusion

Despite producing vitamin D–rich foods and having abundant sunlight, India continues to face high rates of vitamin D deficiency due to lifestyle restrictions, limited dietary intake, cultural practices, poor absorption, biological factors, and insufficient awareness. Addressing the issue requires a multi-dimensional approach—including increased outdoor activities, wider access to fortified foods, targeted supplementation, and national awareness programs. Only through coordinated efforts can India overcome this hidden yet widespread nutritional challenge.

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Interactions Between Entomopathogenic Nematodes and Earthworms: Implications for Soil Functionality and Integrated Pest Management

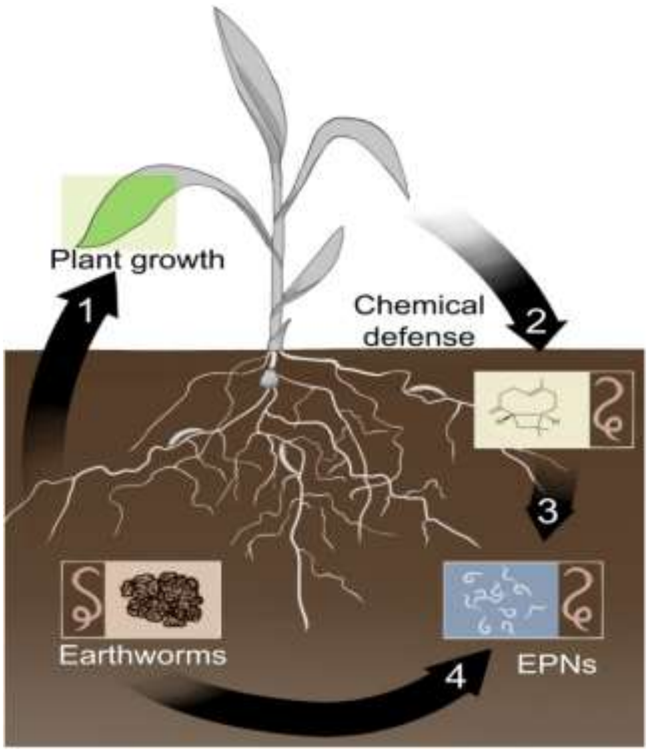
Introduction

On the one hand, earthworms are extremely beneficial to the environment and are essential to the upkeep of healthy soil ecosystems. By loosening and mixing the soil through their burrowing activity, they act as natural soil aerators, promoting better root growth and water infiltration. In addition to enriching the soil with vital nutrients like nitrogen, phosphate, and potassium, their digestion process also makes the soil more fruitful for plants. Earthworm castings, or worm dung, are highly recognized for their capacity to strengthen soil structure and boost plant health. Furthermore, earthworms aid in the breakdown of organic matter, hastening the process and encouraging a more resilient soil nutrient cycle. Their existence is frequently a reliable indicator of the condition of the soil, making them indispensable partners in gardening, agriculture, and horticulture. On the other hand, Insect pests in horticulture, forestry, and agriculture can be effectively managed with the help of worms known as entomopathogenic nematodes (EPNs), which are also environmentally benign. These tiny roundworms infect and destroy a wide range of soil-dwelling insect pests, including those that cause harm to trees and crops, to serve as biological control agents. EPNs are a sustainable alternative to chemical pesticides since they selectively target pests without endangering pollinators, humans, or beneficial species like earthworms. Furthermore, they don't leave any hazardous residues on crops or in the soil, making them environmentally safe. Applying EPNs is simple, they take effect fast, and they can lessen the need for synthetic pesticides, which supports longer-term pest control and better ecosystems.

EPN and earthworm can interact in several ways within Rhizosphre:

1. **Earth worms as Phoretic hosts:** The earthworms, *Eisenia fetida*, serve as potential vectors for enhancing the distribution of nematodes. Campos-Herrera et al. (2006) demonstrated that the passage of *Steinernema feltiae* through the gut of E. fetida significantly impacts the nematodes' mobility (2-15%) and virulence, however the EPNs were non pathogenic to the E. fetida, raising important questions about the dynamics of this interaction.
2. **Enhancement of pathogenicity**: The presence of earth worms enhances the biological control potential of EPNs. Incorporation of earthworms into biological control programs could optimize the dispersal and effectiveness of beneficial organisms, paving the way for more sustainable pest management practices. David et al (2013) proved that earthworms, specifically *Lumbricus terrestris*, improved the efficacy of *Steinernema carpocapsae* in suppressing the pecan weevil, *Curculio caryae*. Chelkha et al. (2013) examined the relationships that have a substantial impact on the virulence and efficacy of entomopathogenic nematodes (EPNs) in biological control between different earthworm species (*Eisenia fetida*, *Lumbricus terrestris*, and *Perionyx excavatus*) and EPNs. The observed differential effects were as follows: *P. excavatus* raised the virulence of *S. feltiae* but decreased that of *H. bacteriophora*, whereas E. fetida reduced the virulence of Steinernema feltiae while enhancing that of Heterorhabditis bacteriophora. Furthermore, depending on the particular earthworm and pathogen species involved, the effects of earthworm conditioning extracts (CEx) on entomopathogens varied greatly and showed potential positive, negative, or neutral effects.
3. **Attraction of EPNs towards plant roots:**

The cooperative interaction between EPN and earth worms implies that earthworms support the biocontrol effectiveness of EPNs against root-feeding pests in addition to improving soil fertility. Fattore et al. (2020) showed that endogeic earthworms greatly increase the ability of entomopathogenic nematodes (EPNs) to infect a variety of cropping systems, especially those with maize roots nearby. The results of the olfactometer-based bioassays and the field mesocosm experiment showed that earthworm activities like casting and burrowing enhance soil characteristics and boost EPN responsiveness to attractants. Specifically, when A. icterica earthworms were present in the mesocosm, the likelihood of G. mellonella larvae becoming infected when positioned near an induced maize root increased by approximately 75%.



Conclusion

The interplay between earthworms and entomopathogenic nematodes (EPNs) within soil ecosystems underscores the potential for synergistic approaches to sustainable agriculture and pest management. Earthworms contribute significantly to soil health through aeration, nutrient cycling, and organic matter decomposition, making them indispensable for maintaining productive and resilient soil systems. Simultaneously, EPNs offer an environmentally friendly alternative for managing soil-dwelling pests, reducing the reliance on chemical pesticides and promoting ecological balance.

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GEOSPATIAL MAPPING OF SOIL EROSION

Introduction

A vital natural resource, soil supports food security, ecosystem stability, and agricultural output. In order to feed the country's rapidly expanding population, soils in India have been continuously and intensively cultivated for decades. Although this kind of intensification has increased agricultural yield, it has also hastened other types of soil deterioration. Among these, soil erosion caused by water continues to be one of the most pervasive and damaging processes affecting Indian landscapes. Indian soils are becoming more susceptible to erosion as a result of both natural and man-made influences. In many regions of the country, soil erosion has increased due to high-intensity monsoonal rains, delicate soil structures, undulating topography, deforestation, agricultural expansion onto marginal lands, and insufficient soil conservation techniques. The issue has been made worse by climate change, which has increased the frequency of intense rainfall events and increased runoff and sediment movement. Fertile topsoil that is rich in organic matter and plant nutrients is consequently lost, which lowers soil fertility, decreases the soil's ability to hold water, and causes crop yields to stagnate or drop. Serious off- site effects of soil erosion include siltation of reservoirs, damage of irrigation equipment, declining water quality, and elevated danger of flooding. These effects have a substantial financial cost and jeopardize the sustainability of water resource and agricultural systems. Effective soil erosion evaluation and management require methods that can capture spatial variability at landscape to regional dimensions due to the spatial expanse and variation of erosion processes throughout India.

Runoff plots and sediment collection are examples of traditional erosion assessment methods that yield accurate estimates at small scales but are labor- intensive, time-consuming, and challenging to extrapolate over vast areas. Geographic information systems (GIS) and remote sensing (RS) have become effective tools for assessing soil erosion in a spatially explicit manner. Geospatial techniques enable systematic mapping of soil erosion risk and promote evidence-based planning for soil and water conservation by combining satellite data, topographical information, soil parameters, and erosion models within a GIS framework.

Concept of Geospatial Soil Erosion Mapping

Using satellite-derived datasets, digital elevation models (DEMs), and erosion prediction algorithms integrated into a GIS framework, geographic soil erosion mapping entails the estimation and spatial depiction of soil loss.

While GIS enables spatial analysis, raster-based computation, and the integration of different datasets, remote sensing offers dynamic information on surface conditions, vegetation cover, and land use. This method facilitates the prioritization of conservation initiatives and enables quantitative assessment of soil erosion across diverse landscapes when paired with erosion models.

Modelling Soil Erosion in an RS-GIS Environment

To quantify soil loss, a variety of erosion models have been created, ranging from empirical to physically based methods. Due to their ease of use, low data needs, and GIS compatibility, the Universal Soil Loss Equation (USLE) and its updated version, the Revised Universal Soil Loss Equation (RUSLE), are the most popular among these in geospatial erosion investigations.

Revised Universal Soil Loss Equation (RUSLE)

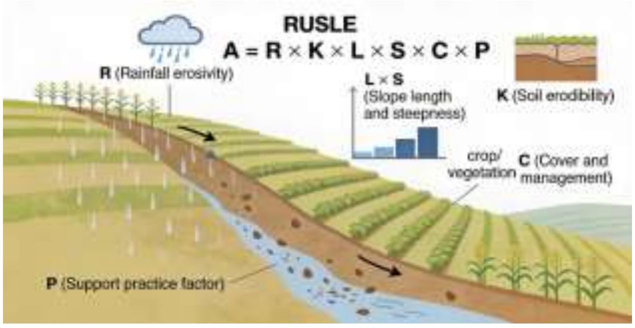
The RUSLE estimates long-term average annual soil loss caused by sheet and rill erosion and is expressed as:

$A = R \times K \times LS \times C \times P$

where:

A = average annual soil loss (t ha^{-1} yr^{-1})
R = rainfall erosivity factor
K = soil erodibility factor
LS = slope length and slope steepness factor
C = cover and management factor
P = support practice factor

Each factor represents a distinct physical or management component influencing erosion and can be spatially represented as a raster layer in GIS.



Estimation of RUSLE Factors Using RS and GIS

⇒ Rainfall Erosivity Factor (R)

Rainfall erosivity measures how easily soil particles can be separated and moved by rainfall. R should ideally be calculated using statistics on rainfall intensity, however in developing countries, such data are frequently unavailable. As a result, mean annual rainfall (mm) is often used in empirical correlations: $R = 79 + 0.363P$
Where, P is mean annual rainfall (mm). Satellite-based rainfall products or rain gauge stations can provide rainfall data, which can then be spatially interpolated in GIS.

⇒ Soil Erodibility Factor (K)

Based on inherent soil characteristics such texture, structure, organic matter concentration, and permeability, the K factor shows how vulnerable soil is to erosion. K values are usually calculated from soil survey data using conventional nomographs or empirical equations. K values are assigned to soil map units in GIS and spatially interpolated into raster layers.

⇒ Topographic Factor (LS)

Runoff velocity and erosion intensity are significantly influenced by topography. The LS factor is calculated from DEMs using GIS-based techniques, combining the impacts of slope length and slope steepness. An equation that is frequently used is:

$$LS = (FA \times CS / 22.13)^m \times (\sin\theta / 0.0896)^n$$

where
FA = flow accumulation,
CS = cell size,
θ = slope angle,
m and n = empirical constants

⇒ **Cover and Management Factor (C)**

The C factor illustrates how crop management and vegetation can prevent erosion. When determining C values using vegetation indices like NDVI, remote sensing is essential. An NDVI-based formulation that is frequently used is:

$$C = \exp\left[-\alpha\left(NDVI/(\beta - NDVI)\right)\right]$$

where α and β are empirical parameters. Lower C values indicate better soil protection.

⇒ **Support Practice Factor (P)**

The P factor takes into consideration soil protection techniques like bunding, terracing, and contour farming. Owing to a lack of spatial data, P values are frequently allocated using standard standards based on land use and slope categories.

GIS-Based Integration and Soil Loss Mapping

In order to calculate spatially distributed soil loss values, all RUSLE factor layers are prepared as raster datasets with uniform resolution and projection. GIS raster algebra is then used to multiply these layers, producing a soil erosion map that is categorized into erosion severity classes such as low, moderate, high, and very high risk. These spatial outputs offer a clear foundation for identifying erosion hotspots and prioritizing areas for soil and water conservation interventions.

Applications in Indian Context

In a variety of Indian agro-ecological regions, such as the Deccan Plateau, Western Ghats, Shivalik foothills, and semi-arid tracts, geographic mapping of soil erosion has been extensively used. Research continuously shows that a tiny area of land contributes disproportionately to the overall loss of soil, underscoring the significance of focused conservation efforts.

In order to prioritize interventions such contour bunding, terracing, vegetative barriers, and afforestation, watershed management programs frequently employ RS-GIS-based erosion maps. These maps support soil conservation programs, sustainable intensification techniques, and land-use planning at the policy and planning levels.

Limitations and Challenges

RUSLE-based geospatial erosion modeling has limitations despite its broad applicability: the model does not explicitly simulate individual storm events or gully erosion; instead, it estimates long-term average soil loss; the accuracy of the model is largely dependent on the quality of the input data and the assumptions used for factor estimation; and ground validation is still necessary to increase reliability.

Conclusion

A reliable and scalable method for evaluating erosion risk across diverse landscapes is the geospatial mapping of soil erosion using remote sensing and GIS. Models like RUSLE allow for the spatially detailed calculation of soil loss by including rainfall, soil, topography, and vegetation data inside a GIS framework. These evaluations help make well-informed decisions on sustainable land-use planning, watershed management, and soil conservation. RS-GIS-based soil erosion mapping is an essential tool for safeguarding soil resources and guaranteeing long-term agricultural sustainability in the light of India's growing land degradation and climatic unpredictability.

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BOTANICAL PESTICIDES: TRADITIONAL WAY OF PEST MANAGEMENT

Abstract

Agriculture has been fundamental to human civilization, yet effective pest management remains a persistent challenge affecting food security, environmental health, and economic stability. The extensive use of synthetic pesticides has contributed to increased crop productivity; however, their long-term and indiscriminate application has resulted in serious concerns such as environmental pollution, human health risks, pest resistance, and loss of biodiversity. These drawbacks have intensified the search for sustainable and eco-friendly alternatives. Botanical pesticides, derived from plant sources and deeply rooted in traditional agricultural knowledge, have emerged as promising substitutes due to their biodegradability, reduced environmental persistence, and relative safety to non-target organisms. Harnessing traditional knowledge alongside scientific validation can play a crucial role in developing environmentally responsible pest management strategies for future food security.

Keywords: Botanical pesticides; Sustainable agriculture; Traditional knowledge; Integrated pest management; Neem; Eco-friendly pest control.

Introduction

Agriculture, as a cornerstone of human civilization for millennia, has perpetually faced the challenge of pest management, a critical factor influencing food security and economic stability. The escalating global population has intensified the demand for food, leading to an increased reliance on synthetic chemicals for rapid and effective pest and disease control (Lengai et al., 2019). However, this widespread adoption of synthetic pesticides has come at a considerable cost, manifesting in detrimental impacts on human health, environmental pollution, and the emergence of pesticide-resistant strains. Consequently, there is a pressing need for sustainable and eco-friendly alternatives to conventional chemical pesticides (Hassan et al., 2024). Botanical pesticides, derived from plants, offer a promising solution due to their biodegradability, reduced environmental persistence, and lower toxicity to non-target organisms (Haritha et al., 2021).

These natural compounds exhibit diverse modes of action, including antifeedant effects, growth inhibition, repellence, and direct toxicity to pests, making them valuable components of integrated pest management strategies.

Neem

Neem has drawn attention as a botanical insecticide because of its many pest-repelling, oviposition, and feeding deterrent properties. Neem extract is easy to make at home and spray, and if you're pressed for time, its goods are also sold. Neem has active ingredient known as azadirachtin which is responsible for the insecticidal property. Azadirachtin exerts its insecticidal activity through multiple modes of action. These include strong antifeedant effects, disruption of normal morphological development, and significant alterations in biological fitness. It also leads to reduced fecundity, suppressed growth, and repulsion of oviposition, and in some cases can even cause sterilization of the target insects (Zhang *et al.*, 2018) (Boulahbel *et al.*, 2015).

Different ways of using neem

- The production of Neem seed kernel extractions was used against locust attack. (Senthil-Nathan and Sengottayan, 2015).
- Neem-based formulations can be effectively used against a variety of insect pests, including the pod borer of chickpea, potato cutworms, and the brinjal fruit and shoot borer.
- In addition to field applications, neem also serves as a natural fumigant for managing storage pests. Several stored-product insects—such as weevils, flour beetles, bean-seed beetles, and potato moths—have been reported to be highly susceptible to the fumigant properties of neem.
- The use of neem extract for controlling crop pests and diseases is a long-standing organic farming practice among the Malayali tribe of the Kolli Hill (Kanagasabapathi and Sakthivel 2019). Their traditional knowledge highlights the effectiveness of neem as an eco-friendly and sustainable pest management tool.

Various neem-based products available in market are neem seed kernel extract and neem oil. These are available at market by various tradenames.

Nicotine

Nicotine is an active ingredient found in tobacco leaves, is an excellent biopesticide. Since 1690, the insecticidal effects of nicotine have been investigated. Because of its short environmental persistence and target pest selectivity, nicotine is commonly considered a potential alternative to traditional insecticides for crop protection and public health (Gudeta *et al.*, 2021). It acts as contact poison, which kills the insects rapidly within hour. It acts as neurotoxin in insect nervous system causing death of insect. It has emerged as one of the most celebrated active compounds extracted from plants.

How farmers use nicotine?

- Nicotine is one of the oldest known plant origin insecticidal activities. Long before knew of nicotine alkaloid in tobacco, *Nicotiana tabacum* L., the latter was being used as a dust or water extract to control phytophagous insects, some three hundred years ago (Rana *et al.*, 2015).
- An extract is obtained from tobacco leaves mixed with water at 1:30 ratio and sprayed in crops like thenai, samai, varagu, and panivaragu to control the pests by tribal farmers in Tamil Nadu.

- Spraying boiled tobacco extract over vegetable crops for control of pests is traditional pest management practice by farmers of Meghalaya (Firake *et al.*, 2013).
- In tribal parts of Chhattisgarh farmers use nicotine paste which is originally used as oral dentifrice, to make a spray by dissolving it in water then they spray the solution after first emergence of brown planthopper in paddy crop.

Moringa

Moringa is native to the sub-Himalayan tracts of India. Moringa is a tree widely distributed in the tropics, being resistant to drought and able to grow in poor soils. Its seeds contain a lectin called WSMoL (water-soluble *M. oleifera* lectin), which showed antibacterial activity (Moura *et al.*, 2015, 2017) and nematicidal effects (Medeiros *et al.*, 2018), and was reported to be an insecticidal agent against mosquito eggs and larvae (Coelho *et al.*, 2009; Santos *et al.*, 2012, 2020).

Moringa in multiple ways

- Moringa leaf extract is traditionally used in chili cultivation for managing pests such as thrips and mites, owing to its natural insecticidal and repellent properties.
- Similarly, extracts prepared from moringa bark are commonly applied to control pumpkin beetles and dusky cotton bugs in gourd crops. These leaf and bark formulations serve as effective indigenous botanical pesticides, widely practiced by farming communities in Tamil Nadu. Their use reflects local knowledge and sustainable pest-management practices that rely on readily available, eco-friendly plant resources. (Ranjith and Arivudainamb, 2019).
- Moringa seed powder, when dusted over sacks containing wheat grains or flour, has been found to significantly reduce infestations of the Mediterranean flour moth and the red flour beetle. This traditional practice demonstrates the potential of moringa seed derivatives as an effective botanical protectant for stored products. (Salem *et al.*, 2020).

Garlic

Garlic (*Allium sativum*) is widely recognized not only as a culinary and medicinal plant but also as an effective natural biostimulant in agriculture. The bioactive compounds present in garlic—such as allicin, ajoene, and various sulfur-containing molecules—possess strong bactericidal and fungicidal properties, which help safeguard plants from a wide range of microbial infections.

How to incorporate garlic extract for pest management?

- Garlic formulations are generally safe and suitable for foliar application on most crops. However, they should not be sprayed on legumes, as these plants may exhibit sensitivity to certain sulfur compounds present in garlic.
- For all other crops, direct leaf application can be an efficient method to deliver its protective and growth-promoting benefits. The garlic has a non-toxic mode of action for repelling target birds and insects (Pavela, 2016).
- It is used in organic farming as a preventive substance, due to its repellent action against pest arthropods (mites, aphids, moths, ter mites, beetles, red spider mites, mosquito larvae, etc.) and snails.

Garlic is not active against useful arthropod (bees, bumblebees, ladybugs, spiders, etc.). In order to protect plants against some species of nematodes, garlic is added to the soil directly. Garlic essential oil was demonstrated to possess insecticidal activity against several grain storage insects (Plata-Rueda *et al.*, 2017).

Karanj

Karanj (*Pongamia pinnata*) is widely recognized as an important medicinal as well as pesticidal plant, valued for its broad spectrum of biological activities. Different parts of the plant—particularly the seeds, the oil extracted from them, and the seed cake—exhibit significant insecticidal and pesticidal properties. These effects are largely attributed to karanjin, a major furanoflavonoid present in the seeds, which acts as a potent bioactive compound responsible for disrupting the growth, feeding behavior, and survival of various pest species. Karanj oil has been extensively used in botanical pest management due to its effectiveness against a wide variety of agricultural and household insect pests. It has shown strong efficacy against shoot and fruit borers, leaf miners, aphids, whiteflies, planthoppers, leafhoppers, mites, leaf-feeding beetles, and several storage pests. Apart from the oil, leaf extracts of Karanj have also demonstrated considerable insecticidal potential. These extracts contain multiple bioactive phytochemicals that exhibit antifeedant, repellent, ovicidal, and growth-inhibiting effects on a range of insect species. Their activity has been reported against several economically important pests, reinforcing the role of *Pongamia pinnata* as a valuable component in eco-friendly pest management strategies. (Kumar *et al.*, 2006).

Conclusion

Agriculture has always been central to human survival, but its success depends heavily on how effectively pests are managed without harming the environment. The long reliance on chemical pesticides has undoubtedly helped increase crop yields, yet their negative impacts—ranging from soil and water pollution to health hazards and biodiversity loss—have become impossible to ignore. These consequences highlight an urgent need for safer, sustainable alternatives that protect both crops and the ecosystems that support them. Botanical pesticides, rooted in traditional knowledge and supported by modern research, offer such a solution. Plants like neem, tobacco, moringa, garlic, and karanj demonstrate the remarkable potential of nature-based pest management. Together, these botanicals illustrate how effective, eco-friendly pest control can be achieved using locally available resources. In moving forward, integrating botanical pesticides into modern farming systems can help build resilient, sustainable food production for future generations.

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FEEDING CROPS WITH PRECISION: THE ROLE OF SLOW-RELEASE N FORMULATIONS

Introduction

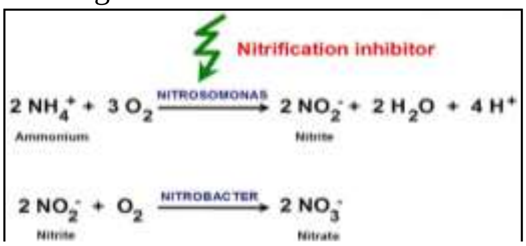
Nitrogen use efficiency (NUE) is a parameter which is an indicative of the extent of utilization of applied N by crops. Nearly 90% of N-fertilizers upon application in soil undergoes dissociation to form NH_4^+ directly or is converted into NH_4^+ through urea hydrolysis. Since most of the agricultural crops prefers to absorb N as NO_3-N, this signifies the importance of nitrification process in crop nutrition which involves enzymatic oxidation of NH_4^+-N to NO_3-N mediated by nitrifying bacteria (mainly *Nitrosomonas* and *Nitrobactor*). However, use efficiency of fertilizer N is very low i.e. not exceeding 35% in rice and 40-60% in other crops. Such low NUE is mainly attributed to loss of N fertilizers through volatilization (alkaline and calcareous soil), fixation (clay soil rich in 2:1 clay minerals), leaching (coarse-textured sandy soil) and denitrification (submerged soil or arable soil with decomposable organic residues). So, synthetic N fertilizer formulations are commercially available that aids slow release of N into soil matching with the crop demand thereby minimize N loss and improve nitrogen use efficiency.

Slow-release N fertilizers (SRFs)

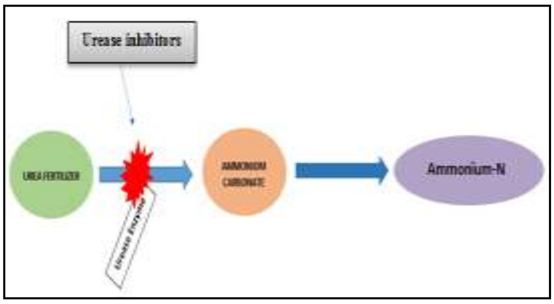
Slow-release N fertilizers are the N fertilizer formulations that are either sparingly soluble in water or delays the process of nitrification and urea hydrolysis thereby facilitate slow release of N into the soil in synchronization with crop need and improve nitrogen use efficiency. This makes SRFs a good alternative to conventional fertilizers owing to their ability to reduce the wastage of fertilizers that causes serious environmental hazard, affecting both soil and water ecosystems, and to improve nutrient use efficiency of crops by increasing their nutrient uptake, with enhanced yields in terms of quantity and quality.

Types of slow-release N fertilizers

a) **Nitrification inhibitors:** These are the synthetic N formulation that delays/inhibits nitrification (biological oxidation of ammonium-N to nitrate-N) by regulating the activity of *Nitrosomonas* bacteria thereby prevents denitrification and leaching loss of nitrate-N.



a) **Urease inhibitors:** These are the compounds that delays/inhibits urea hydrolysis (break down of urea to ammonium-N) by regulating the activity of urease enzyme. By slowing urea hydrolysis, these inhibitors allow more nitrogen to be incorporated into soil, benefiting crop growth and reducing environmental N losses through volatilization and fixation.



b) **Coated N fertilizers**: These are the synthetic N formulation that facilitate slow release of N into soil due to the impermeable coating over the surface of N fertilizer.

c) **N fertilizers with low solubility:** There are some commercial N fertilizers that have high N content (30-38 % N) with low water solubility (10-15 %) that in turn facilitate slow release of N to soil.

d) **Sparingly soluble N minerals:** There are some naturally occurring N minerals that are sparingly soluble in water, hence can be exploited as a source of slow-release N fertilizers.

Ideal characteristics of slow-release N fertilizers

- Should not impart residual toxicity in soil, also should be non-toxic to crop and microorganisms
- Should release N in a slow or controlled rate in synchronization with crop need
- Should meet crop nutritional demand at critical growth stages
- Should not completely block the nitrification or urea hydrolysis rather should regulate by delaying the activity of *Nitrosomonas* and urease enzyme.
- Should be stable in its inhibitory action
- Should persists in soil for adequate period of time.
- Should be cost effective and commercially available to farmers.
- Should be physically and chemically compactible to be mixed with fertilizer formulations

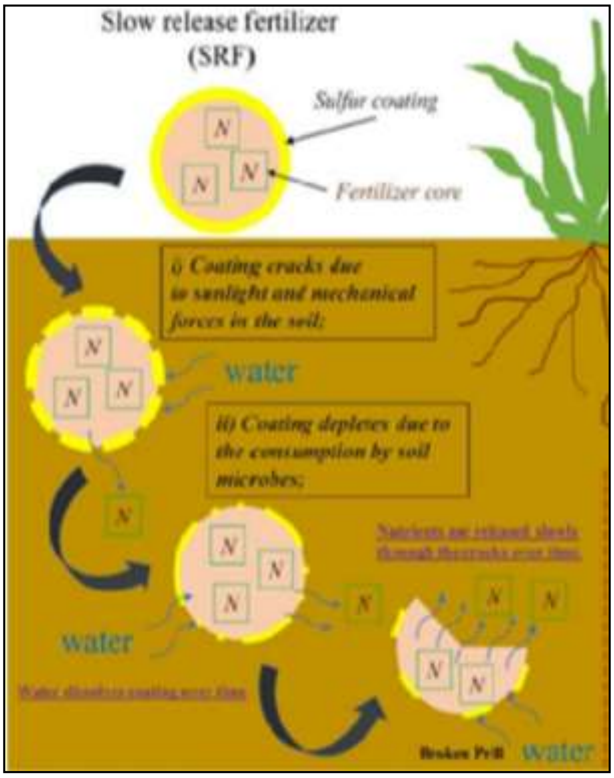


Fig 1. N release in S coated Fertilizers (Irfan *et al.*, 2018)

Advantages

- Minimizes N loss through leaching, denitrification fixation and volatilization

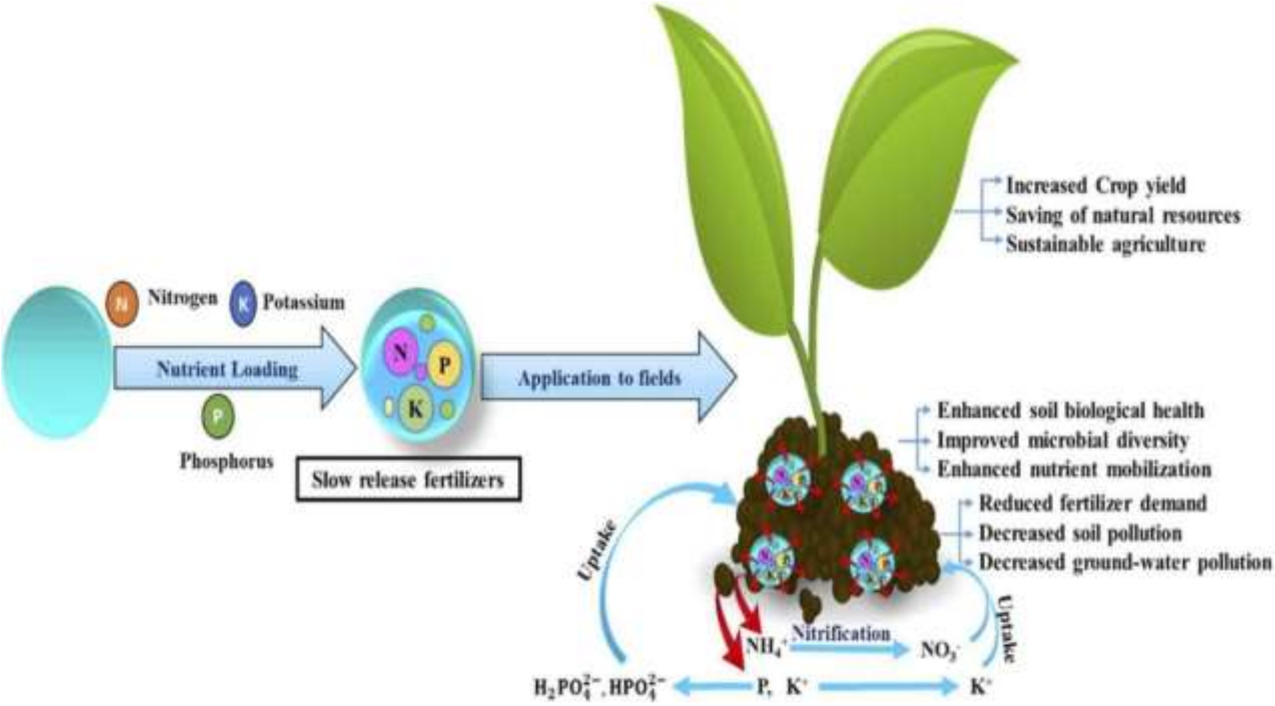


Fig 2. Flow diagram depicting the potential benefits of SRFs in soil (Priya *et al.*, 2024)

- by keeping N in form NH_4^+-N for long time and aids slow release of N as per crop demand.
- Favours partial ammonium nutrition in crops because plant needs less energy to incorporate ammonium-N into amino acids.
- Meets the nitrogen requirement during critical growth stages of crops
- Improves nitrogen use efficiency of crops
- Avoid frequent application of N fertilizers (top dressing)
- Prevent contamination of soil and ground water with high nitrate-N level
- Avoid luxury consumption of nitrogen by crop
- Prevent harmful effect of N toxicity in crop (seed germination, root emergence)

Conclusion

Slow-release N fertilizers serve as an excellent alternative to commercial synthetic fertilizers mainly urea. As these formulations slowly releases N over the growing season, plants can absorb most of the applied nitrogen efficiently without any loss improving NUE. It also promotes a diverse and abundant beneficial microbial community by providing a steady supply of nutrients, which enhance soil function and health without any residual toxicity. Some crucial factors such as selection of proper formulations and dose of application specific to crops, compatibility with chemical fertilizers should be given importance for successful use of slow-release fertilizers under field conditions.

Types	Examples	Mechanism
Nitrification inhibitors	N serve/nitrapyrin (2-chloro, 6-trichloromethyl pyridine) AM (2-amino, 4-chloro, 6-methyl pyrimidine) DCD (Dicyandiamide) ATC (4-amino, 1,2,4-triazole) DMPP (3,4-dimethyl pyrazole phosphate)	Tie-up with copper - critical metal required for activity of *Nitrosomonas*
	Oil cakes (neem cake, karanj cake, neem oil)	Production of alkaloids
	Sulphur compounds (carbon disulphide, ammonium thiosulphate)	Formation of sulphuric acid
	Calcium carbide	Production of acetylene (C_2H_2)
Urease inhibitors	N-(n-butyl) thiophosphoric triamide (NBPT) Phenyl phosphorodiamidate (PPD) Phenyl mercuric acetate (PMA)	Tie up with nickel - a metallic cofactor required for activity of urease.
	Quinone Benzoquinone Hydroquinone	Binds to cysteine residues altering the structure and function of urease enzyme
Coated N fertilizers	Neem coated urea, Lac coated urea Sulphur coated urea	Slow diffusion of N due to coating
N fertilizers with low solubility	Urea form (urea + formaldehyde) Urea-Z (urea + acetaldehyde) IBDU (Isobutyledene diurea) CDU (Crotolydene diurea) Oxamide, Thiourea	Low water solubility
Sparingly soluble N minerals	Struvite (Magnesium ammonium phosphate; Mg NH_4 $PO_4.6H_2O$)	Sparingly soluble in nature
Composite formulation	Agrotain plus: DCD + NBPT Super urea: Urea + DCD + NBPT	Inhibits nitrification and urea hydrolysis

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EVOLUTION OF AGRICULTURAL EXTENSION FROM TRADITIONAL METHODS TO DIGITAL PLATFORMS

INTRODUCTION

Agricultural extension plays a crucial role in agricultural and rural development, acting as a link between agricultural research institutions and farming communities. The main goal of extension is to share scientific knowledge, advanced technologies, and optimal management practices with farmers to improve productivity, profitability, and sustainability. Over time, extension systems have evolved continuously in response to changing agricultural conditions, farmer requirements, and technological advancements. In the early phases, agricultural extension primarily relied on traditional, face-to-face communication methods, where extension agents engaged directly with farmers through farm visits, meetings, and demonstrations. These approaches were effective in fostering trust and encouraging the adoption of fundamental agricultural innovations. However, the rapid population growth, increasing strain on natural resources, climate variability, market fluctuations, and diversification of farming systems have significantly heightened the information demands of farmers.

Simultaneously, advancements in information and communication technologies (ICTs), especially the widespread access to mobile phones and internet services, have opened new avenues for delivering extension services. Consequently, agricultural extension has progressively transitioned from traditional methods to digital platforms that facilitate quicker, broader, and more interactive information dissemination. This change signifies a critical phase in the development of agricultural extension, illustrating a paradigm shift from conventional advisory methods to technology-driven, farmer-focused extension systems.

TRADITIONAL AGRICULTURAL EXTENSION SYSTEM

The traditional agricultural extension system serves as the earliest and most fundamental method for conveying agricultural knowledge from research institutions to farming communities. This system predominantly operated in a top-down manner, where technologies and recommendations formulated by scientists were communicated to farmers via extension personnel. The basic premise was that farmers were devoid of scientific knowledge and needed expert advice to enhance their farming practices. Traditional extension placed significant emphasis on interpersonal communication, positioning the extension worker as the pivotal figure in the knowledge dissemination process. Extension personnel frequently visited villages and farms to identify issues related to crops, soils, pests, and livestock, and to propose suitable solutions.

These engagements enabled extension workers to acquire a profound understanding of local agro-climatic conditions, cropping patterns, and the socio-economic challenges encountered by farmers.

A range of extension methods were utilized within the traditional system.

1. Farm and home visits provided personalized guidance and problem resolution.
2. Method demonstrations illustrated to farmers how to implement a new practice step by step, while result demonstrations showcased the advantages of adopting improved technologies.
3. Group meetings and training sessions encouraged collective learning and dialogue among farmers.
4. Field days, campaigns, and exhibitions raised awareness about new technologies and government initiatives.
5. Mass media tools, including radio broadcasts, farm magazines, leaflets, and television programs, complemented interpersonal methods by reinforcing extension messages.

One of the most significant advantages of the traditional extension system was its focus on fostering human relationships and building trust. Farmers were more inclined to embrace new practices when they had faith in the extension worker. Ongoing follow-up and direct interaction facilitated a better understanding, rectification of errors, and gradual changes in behavior. This system was instrumental in the effective dissemination of Green Revolution technologies, including high-yielding varieties, chemical fertilizers, and irrigation methods. However, despite its positive contributions, the traditional extension system encountered considerable structural and operational challenges. The growing number of farmers in relation to the limited extension personnel made regular communication challenging. Extension activities demanded considerable time, human resources, and financial investment, which diminished overall efficiency. The dissemination of information was frequently slow, seasonal, and generalized, complicating the response to emerging challenges such as climate variability, pest infestations, and market changes. Additionally, the unidirectional flow of information restricted farmer engagement and feedback.

As agriculture evolved to become more intricate, diversified, and market-driven, it became clear that the traditional extension system was inadequate to fulfill the increasing and dynamic information requirements of farmers. These shortcomings generated a significant demand for innovative, quicker, and more inclusive extension methods, leading to a shift towards digital agricultural extension.

NEED FOR TRANSFORMATION IN EXTENSION APPROACHES

The necessity for transforming agricultural extension methods has arisen due to significant shifts in the agricultural sector, rural communities, and the global economy. Although traditional extension systems established a solid groundwork for the dissemination of technology, they have increasingly proven insufficient in tackling the intricate, varied, and swiftly evolving challenges that contemporary farmers encounter. Modern agriculture extends beyond mere crop production; it encompasses climate risk management, market intelligence, value addition, post-harvest processing, and sustainable resource utilization, all of which necessitate timely and specialized information.

A primary catalyst for transformation is the growing disparity between the number of farmers and the availability of extension personnel. With a limited workforce, it has become nearly impossible for extension agents to maintain regular and effective communication with all farmers. Consequently, many farmers, particularly small and marginal ones in remote and hard-to-access regions, have remained underserved. This scenario has called for extension strategies capable of reaching a large number of farmers simultaneously without sacrificing the quality of information.

Another critical factor driving the need for change is the rising variability and uncertainty in agriculture, especially as a result of climate change. Unpredictable rainfall patterns, recurrent droughts and floods, pest and disease outbreaks, and soil degradation have heightened production risks. Farmers now require real-time, location-specific, and weather-related advisories, which traditional extension methods are unable to deliver in a timely manner. Delayed information frequently leads to crop losses and diminished incomes. The market orientation of agriculture has heightened the necessity for a transformation in extension methodologies. Farmers are increasingly expected to adapt to market demands, price variations, quality benchmarks, and consumer preferences.

Traditional extension systems primarily concentrated on production elements, offering minimal focus on market intelligence, value chains, and agribusiness prospects. Consequently, farmers have started to seek advice on marketing, storage, processing, and entrepreneurship, necessitating a more holistic and responsive extension framework. Moreover, the evolving socio-economic profiles of farmers have further fueled the demand for transformation. Younger farmers and rural youth are generally more educated, technology-savvy, and information-driven. They anticipate prompt, dependable, and easily accessible information via modern communication platforms. Women farmers, who are crucial to the agricultural sector, also require extension services that are adaptable, inclusive, and customized to their unique needs and time limitations.

The swift progress of information and communication technologies (ICTs) has created a significant opportunity to tackle these emerging challenges. The extensive use of mobile phones, internet access, and digital media in rural regions has opened new pathways for delivering extension services in a quicker, more interactive, and cost-efficient manner. Policymakers and extension organizations have acknowledged that the integration of digital tools with existing extension frameworks could greatly improve outreach, efficiency, and overall impact. Therefore, the transformation of agricultural extension strategies has become essential to ensure relevance, effectiveness, and sustainability. This transition has paved the way for the rise of digital agricultural extension, which seeks to enhance traditional methods while addressing their shortcomings and fulfilling the changing requirements of farmers in a dynamic agricultural landscape.

EMERGENCE OF DIGITAL AGRICULTURAL EXTENSION

The advent of digital agricultural extension signifies a crucial development in the progression of extension systems, propelled by swift advancements in information and communication technologies (ICTs) and their growing reach into rural regions. Digital agricultural extension encompasses the utilization of digital tools, platforms, and technologies to distribute agricultural information, offer advisory services, and foster interaction among farmers, researchers, extension personnel, and other participants in the agricultural value chain. The extensive availability of mobile phones, particularly smartphones, has been instrumental in the proliferation of digital extension. Mobile-based advisory services, including SMS alerts, voice messages, interactive voice response systems (IVRS), and mobile applications, empower farmers to obtain timely information pertinent to crop production, weather forecasts, pest and disease management, nutrient application, and market prices. These services assist farmers in making informed decisions during critical phases of crop development, thus mitigating risks and enhancing productivity.

The growth of internet connectivity and social media platforms has further bolstered digital extension initiatives. Platforms such as WhatsApp, YouTube, and Facebook have emerged as favored channels for disseminating agricultural videos, images, success stories, and expert advisories. Farmer groups and online communities facilitate peer-to-peer learning, promote experience sharing, and enable swift problem-solving through interactive communication. Web portals and e-extension platforms operated by government agencies, universities, and private entities offer access to a diverse array of agricultural resources and expert consultations. The advent of advanced digital technologies has introduced a new aspect to extension services. Remote sensing, geographic information systems (GIS), artificial intelligence (AI), and decision-support systems facilitate the creation of location-specific and data-driven advisories. These technologies bolster precision agriculture by providing accurate recommendations regarding irrigation scheduling, fertilizer application, and pest monitoring. Furthermore, digital platforms enable the amalgamation of weather data, soil health information, and market intelligence into a unified advisory system.

Digital agricultural extension has markedly enhanced the speed, reach, and efficiency of information dissemination. In contrast to traditional methods, digital platforms can cater to a large number of farmers simultaneously at a relatively low cost. They also promote two-way communication, allowing farmers to request clarifications, offer feedback, and report field issues in real time. This interactive characteristic improves farmer engagement and amplifies the relevance of extension messages. Nevertheless, the rise of digital extension does not seek to entirely replace traditional extension systems. Rather, it serves to complement conventional methods by addressing their limitations and improving their effectiveness. By integrating personal contact methods with digital tools, extension systems can become more inclusive, responsive, and centered around farmers, thereby meeting the evolving needs of modern agriculture.

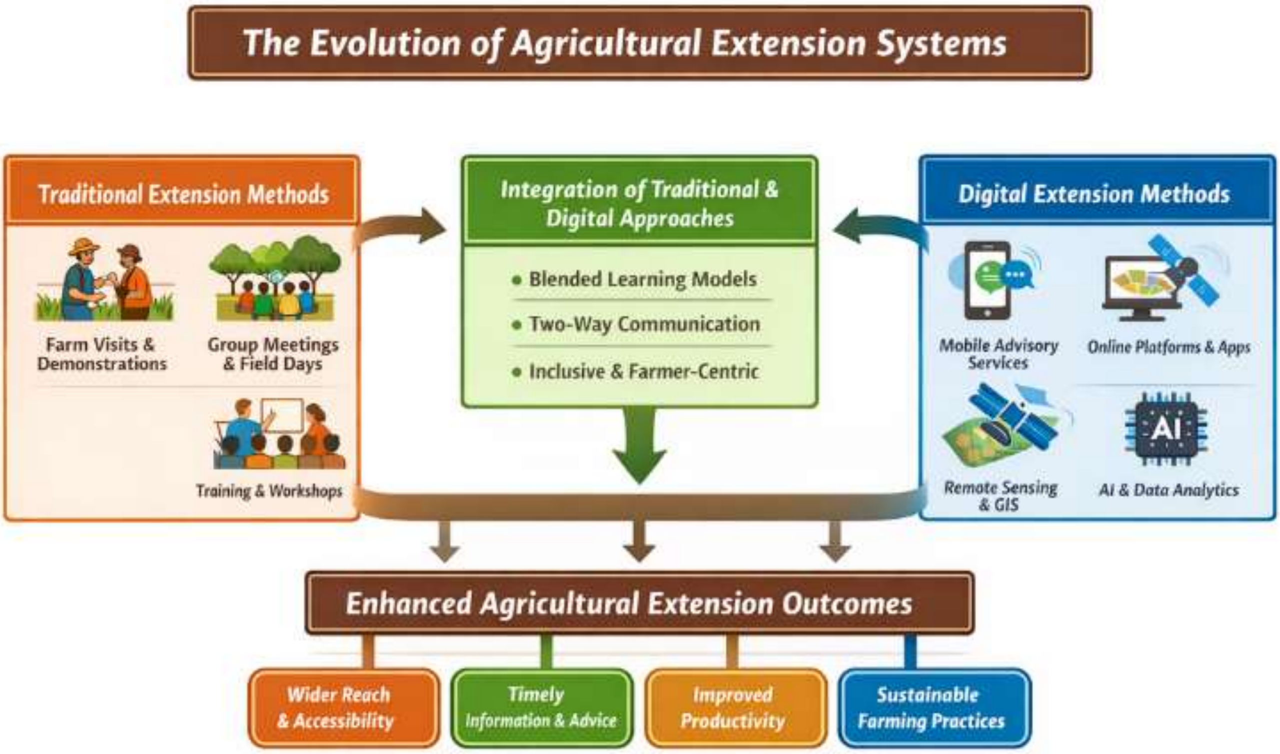
INTEGRATION OF TRADITIONAL AND DIGITAL EXTENSION METHODS

The combination of traditional and digital extension methods signifies a strategic advancement in agricultural extension systems, acknowledging that no single method can sufficiently meet the varied and evolving information requirements of farmers. Traditional extension techniques and digital platforms are not exclusive; instead, they complement each other. An integrated extension system aims to leverage the advantages of both methods to establish a more responsive, efficient, and inclusive framework for the dissemination of agricultural knowledge.

Traditional extension techniques—such as farm and home visits, group meetings, demonstrations, field days, and farmer training—remain highly relevant in rural settings. These techniques are fundamentally based on interpersonal communication and experiential learning, which are vital for fostering trust, comprehending farmers' socio-economic circumstances, and encouraging behavioral change. In-person interactions enable extension agents to observe on-the-ground realities, accurately diagnose issues, and offer context-specific solutions. Such personal engagement is especially crucial for the introduction of new or complex technologies that necessitate hands-on assistance.

Nevertheless, the efficacy of traditional extension methods is frequently limited by a lack of manpower, financial resources, and time. Extension workers are unable to maintain regular contact with all farmers, particularly in areas with large farming populations or challenging geographical conditions. This is where digital extension methods assume a vital supportive role. Digital tools such as mobile advisories, smartphone applications, social media platforms, and online portals facilitate the swift dissemination of information to a vast number of farmers at a relatively low cost. They ensure ongoing communication beyond physical visits and assist in overcoming spatial and temporal obstacles.

An integrated extension approach utilizes digital platforms to enhance, complement, and maintain the messages conveyed through conventional methods. For instance, information disseminated during a field demonstration can be augmented with



follow-up SMS notifications, brief instructional videos, or voice messages at crucial crop stages. This reinforcement aids in memory retention, improves comprehension, and boosts the chances of adoption. Furthermore, digital tools enable extension organizations to customize advisories according to crop stage, weather conditions, and local requirements, rendering extension services more accurate and responsive to demand.

Integration also fortifies two-way communication and participatory learning. Farmers can utilize digital platforms to report field issues, share images or videos of pest and disease symptoms, and request prompt expert guidance. This interactive process fosters farmer engagement and transforms extension from a unidirectional transfer of technology into an ongoing learning and feedback mechanism. Insights obtained from digital interactions can further assist extension personnel in organizing targeted field visits, training sessions, and demonstrations, thereby maximizing the use of limited resources.

The integrated model is especially effective in meeting the needs of various farmer groups. While traditional methods ensure inclusivity by reaching farmers with limited digital skills, digital platforms serve younger, educated, and tech-savvy farmers. Women farmers, who frequently encounter mobility and time limitations, benefit from digital advisories that can be accessed at their convenience, while still depending on traditional group meetings for collective learning and confidence building. Therefore, integration aids in bridging the digital divide rather than exacerbating it. From an institutional standpoint, the amalgamation of traditional and digital extension techniques fosters improved coordination among research institutions, extension agencies, and farmers. It facilitates alignment with other rural development efforts and promotes public–private partnerships in the delivery of extension services. By merging credibility, trust, and personal interaction with speed, scalability, and innovation, an integrated extension system presents itself as a sustainable and farmer-focused approach. The combination of traditional and digital extension methods signifies a practical and progressive strategy for enhancing agricultural extension systems. This hybrid model not only boosts the efficiency and effectiveness of extension services but also guarantees resilience, adaptability, and inclusiveness in response to emerging agricultural challenges.

ADVANTAGES OF DIGITAL AGRICULTURAL EXTENSION

1. Digital extension facilitates broader outreach by connecting with a significant number of farmers across various regions simultaneously.
2. It guarantees the timely and real-time delivery of information, which is essential during fluctuations in weather, outbreaks of pests and diseases, and abrupt changes in the market.
3. Digital platforms offer cost-efficient extension services by minimizing the necessity for frequent physical visits and reducing operational expenses.
4. Farmers obtain location-specific and tailored advisories that consider crop type, season, soil conditions, and weather data.
5. Two-way communication is improved, enabling farmers to pose questions, seek clarifications, and easily provide feedback.
6. Digital tools encourage ongoing learning, as advisories, videos, and messages can be accessed repeatedly at the convenience of the farmers.
7. The incorporation of multimedia content such as audio, images, and videos enhances the understanding and retention of extension messages.
8. Digital extension aids farmers in making better decisions, assisting them in managing risks and adopting advanced technologies.
9. It reinforces market-oriented extension by supplying information regarding prices, demand trends, storage, processing, and value addition.

CHALLENGES OF DIGITAL AGRICULTURAL EXTENSION

1. The digital divide continues to pose a significant challenge, stemming from unequal access to smartphones, internet connectivity, and digital infrastructure in rural regions.
2. Insufficient digital literacy among small, marginal, and elderly farmers hampers the effective utilization of digital platforms.
3. Language barriers, along with a scarcity of locally relevant content, diminish the effectiveness of digital advisories.
4. The overwhelming amount of online information can lead to confusion and increase the risk of misinformation among farmers.
5. Concerns regarding credibility and trust arise when digital advisories lack proper verification or authentication.
6. Technical difficulties, such as inadequate network coverage, power outages, and software malfunctions, hinder service delivery.
7. Data privacy and security issues surface due to the collection and utilization of farmers' personal and farm-related information.
8. Digital platforms may not adequately meet the needs of farmers who favor personal interaction and experiential learning.
9. A lack of coordination among various digital platforms can result in the duplication and fragmentation of extension services.

CONCLUSION

The progression of agricultural extension from conventional techniques to digital platforms signifies a significant transformation in the spread of agricultural knowledge. Traditional extension methods, such as farm visits, demonstrations, group meetings, and field days, played a crucial role in establishing trust, nurturing relationships, and assisting farmers in adopting enhanced practices. They offered direct, hands-on support that proved highly effective for learning new technologies and tackling location-specific challenges. Nevertheless, these traditional methods had limitations in terms of reach, were time-consuming, and incurred high costs, making it challenging to satisfy the rapidly increasing and varied information requirements of farmers.

The emergence of digital agricultural extension has mitigated many of these constraints by offering timely, scalable, and interactive advisory services. Mobile-based advisories, web portals, social media platforms, and advanced tools such as decision-support systems and remote sensing allow farmers to obtain real-time information regarding crop management, weather conditions, pest control, and market opportunities. Furthermore, digital tools facilitate two-way communication, enabling farmers to pose questions, share field observations, and receive expert advice without the need to wait for in-person visits. This not only enhances the speed and efficiency of extension services but also boosts farmer engagement and participation. The integration of traditional and digital extension methods results in a hybrid model centered around farmers, capitalizing on the advantages of both strategies. Traditional methods continue to foster credibility, motivation, and experiential learning, whereas digital platforms enhance outreach, offer ongoing support, and enable tailored advisories.

This integration promotes inclusivity, allowing small and marginal farmers, women, and rural youth to gain benefits irrespective of their levels of digital literacy. Furthermore, it improves resource utilization, planning, and monitoring for extension agencies, while also narrowing the divide between research institutions and farming communities. However, despite its promise, digital extension encounters obstacles such as connectivity challenges, limited digital literacy, language barriers, and issues regarding data reliability and privacy. It is crucial to tackle these challenges through capacity-building initiatives, localized content, and supportive infrastructure to fully harness the advantages of a blended extension system. In summary, the transition from traditional to digital extension signifies not merely a change in tools but a fundamental shift in the delivery of agricultural knowledge. By merging personal interaction with technological advancements, integrated extension systems empower farmers to make well-informed decisions, adopt contemporary practices, boost productivity, manage risks, and enhance their livelihoods. This transformation establishes a foundation for a resilient, inclusive, and future-ready agricultural sector, equipped to address the challenges of a swiftly evolving environment while promoting sustainable rural development.

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INTEGRATING TRADITIONAL WISDOM AND MODERN SCIENCE FOR SUSTAINABLE AGRICULTURE IN UTTARAKHAND

Introduction

Agriculture in the hill regions of Uttarakhand extends beyond economic activity, representing a way of life embedded in local culture, ecology, and collective memory. Farming communities in the Garhwal and Kumaon Himalayas have developed indigenous practices tailored to fragile mountain environments, including steep slopes, thin soils, limited irrigation, and climatic uncertainty. Recognising the significance of hill agriculture for rural stability and livelihoods, the Uttarakhand government has increasingly incorporated it into state development planning. According to a report from PRS Legislative Research, Uttarakhand's Gross State Domestic Product (GSDP) for 2025–26 is projected at Rs 4,29,308 crore, representing a 13% increase over the revised estimate for 2024–25.

Indigenous Knowledge: The Foundation of Hill Agriculture

Indigenous knowledge encompasses locally developed, experience-based understandings of natural resources, farming systems, and ecological processes. In Uttarakhand, this knowledge is transmitted orally across generations and is embedded in daily agricultural practices. Traditional hill farming systems, including Barahnaja (mixed cropping of cereals, pulses, and millets), terraced cultivation, application of farmyard manure (FYM), community-managed irrigation channels (guls/kuhls), and seasonal crop rotations, demonstrate significant ecological insight.

	
Fig 1. Harvesting of Finger Millet	Fig 2. Traditional rice transplanting in a waterlogged paddy field

These practices prioritize food security, soil fertility, and risk reduction under uncertain climatic conditions rather than maximizing short-term yields. Indigenous pest management methods, such as the use of neem leaves, cow urine, ash, and botanical extracts, enable crop protection without harming beneficial insects or soil organisms. Traditional storage structures, including kothars (granaries) and earthen pots, facilitate safe grain storage without chemical preservatives. The value of indigenous knowledge in hill agriculture lies in its context specificity, as it is adapted to local altitude, slope, rainfall patterns, soil type, and socio-cultural conditions. In settings where universal solutions often fail, such localized knowledge enhances resilience and stability.

Scientific Knowledge and Agricultural Modernization

Scientific knowledge, grounded in formal research, experimentation, and standardised technologies, has increasingly shaped agriculture in Uttarakhand through government schemes, extension services, research institutions, and market-linked programmes. Key initiatives include the Soil Health Card Scheme for scientific nutrient management, the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) for irrigation efficiency and water conservation, and the Sub-Mission on Agricultural Mechanisation (SMAM), which facilitates access to machinery suited to hill conditions. The Mission for Integrated Development of Horticulture (MIDH) promotes high-value fruit and vegetable crops, protected cultivation, and quality planting material, while the Agriculture Infrastructure Fund (AIF) supports post-harvest infrastructure and value addition. Risk mitigation and financial inclusion are strengthened through the Pradhan Mantri Fasal Bima Yojana (PMFBY) and the Kisan Credit Card (KCC), complemented by extension services under ATMA and state-led organic and natural farming programmes. Modernisation has led to the widespread adoption of hybrid crop varieties, particularly in horticulture, with crops such as apple, pea, tomato, plum, peach, and pomegranate offering higher yields and better market returns. Under the Uttarakhand Apple Mission (new apple policy), the state actively promotes ultra-dense and high-density apple orchards, providing subsidies of up to 60% and targeting the expansion of around 5,000 hectares under advanced orchard systems. These orchards yield significantly more per hectare than traditional systems and are expected to enhance apple production and farm incomes. Scientific pest management practices, including synthetic pesticides and commercial biopesticides, along with improved seed varieties, plastic mulching, and protected cultivation (polyhouses), have further reshaped hill agriculture.

Fig 3. Apple orchard protected with hail net

Fig 4. Row planting with stake-supported crop management in a tomato field.

However, these approaches often assume reliable irrigation, capital availability, and stable markets, conditions that are not always present in mountain regions, and when applied without adaptation can increase costs, degrade soil health, and deepen dependence on external inputs.

Agricultural Transition and Emerging Challenges

The increasing penetration of scientific and technological interventions has driven a major agricultural transition in Uttarakhand, marked by a shift toward market-oriented and high-value cropping systems. Horticulture has emerged as a central pillar of diversification, supported by policy incentives and farmers' income aspirations. According to the Ministry of Agriculture and Farmers Welfare, horticulture production reached 1,033.427 thousand tonnes in 2025, recovering from 935.103 thousand tonnes in 2024. According to a report from the Japan International Cooperation Agency (JICA), apple production in Uttarakhand declined between 2017-18 and 2019 but recovered to 2017-18 levels by 2019-20, while the area under apple orchards more than doubled during this period. The report also highlights the ongoing expansion of vegetable, fruit, spice, and floriculture crop cultivation across the region's major hill districts. Despite these gains, the transition has intensified multiple and interconnected risks. Over 55% of Uttarakhand's cultivated land remains rainfed, making agriculture highly vulnerable to moisture stress and climate variability. Climate unpredictability in the form of erratic rainfall, unseasonal frost, hailstorms, and rising temperatures poses serious threats to horticulture-based systems, which are often more sensitive than traditional cereal crops. Official assessments by the Ministry of Agriculture and Farmers Welfare and the Indian Council of Agricultural Research highlight increasing vulnerability of horticultural crops to climatic extremes, particularly in hill districts such as Uttarkashi, Chamoli, and Nainital. In contrast, traditional rainfed crops such as millets and pulses, and mixed cropping systems, continue to perform relatively better under low-input and moisture-stressed conditions, providing food security and risk buffering in fragile mountain environments. Structural constraints further compound these risks. Inadequate storage, transport, and marketing infrastructure significantly increase farmers' exposure to price volatility and post-harvest losses. The lack of cold-chain facilities and limited rural storage capacity results in substantial losses of perishable produce, such as fruits, vegetables, and flowers, forcing farmers to sell at sub-optimal prices. This infrastructure gap weakens farmers' bargaining power, amplifies market instability, and disproportionately affects small and marginal producers in hilly regions like Uttarakhand. Ecological concerns have also intensified alongside agricultural modernisation. Increased use of chemical fertilisers and pesticides has contributed to declining soil organic matter, loss of beneficial soil microorganisms, and contamination of water sources. The replacement of traditional crop varieties with uniform hybrids raises concerns about long-term loss of agrobiodiversity. Recognising these risks, Uttarakhand's Organic and Natural Farming programmes emphasise reducing synthetic input use to protect soil and water quality. Hydrological assessments by the Central Ground Water Board, Uttaranchal Region (AAP 2023–24), identify agricultural fertilisers and pesticides as contributors to groundwater contamination in hill areas due to leaching and runoff. Additionally, managing diversified cropping systems with varying nutrient, water, and pest management needs increases labour and knowledge demands, particularly for small and marginal farmers.

Why Integration Matters

The integration of indigenous and scientific knowledge offers a viable pathway to address the emerging challenges in Uttarakhand's hill agriculture. Indigenous practices contribute to sustainability, resilience, and ecological balance, while scientific innovations enhance productivity, disease control, and market connectivity. Integrating traditional soil fertility practices such as FYM, composting, and green manuring with scientific nutrient management can improve soil health while reducing chemical dependency, and combining indigenous pest repellents with scientific Integrated Pest Management (IPM) can lower pesticide use and delay pest resistance. Indigenous mixed-cropping principles can be adapted to modern systems through intercropping, crop rotation, and agroforestry, supported by scientific research, while traditional water management systems combined with rainwater harvesting and micro-irrigation can strengthen water security in hill villages. Traditional seed-saving practices, when integrated with scientific breeding, help maintain genetic diversity while introducing improved traits such as drought tolerance and higher yields. Livestock management benefits from blending local husbandry methods and ethnoveterinary remedies with modern veterinary science, while community-led forest management can be reinforced through scientific biodiversity monitoring and ecosystem restoration. In post-harvest handling, indigenous storage methods such as mud bins and neem leaves, integrated with scientific pest control and cold-chain logistics, reduce losses and enhance food security. Climate adaptation is strengthened by combining traditional risk diversification and local weather forecasting with scientific climate data, early warning systems, and crop modelling. Participatory research models such as farmer field schools further enable two-way learning, fostering community ownership and context-specific, sustainable agricultural development.

Role of Institutions and Policy

The success of knowledge integration depends on supportive institutional and policy frameworks. Extension systems should move beyond top-down technology transfer and adopt participatory approaches that recognize farmers as co-creators of knowledge. Documenting indigenous practices, promoting farmer-to-farmer learning, and incorporating local knowledge into agricultural planning can enhance community ownership. Research institutions should prioritize location-specific innovations rather than universal recommendations. In Uttarakhand, several organizations play a critical role in documenting indigenous agricultural practices. Krishi Vigyan Kendra (KVKs) in districts such as Almora and Uttarkashi record farmers' traditional knowledge through participatory extension and field studies. The Uttarakhand Organic Commodity Board (UOCB) has compiled traditional farming and natural resource management practices to support organic agriculture. Academic platforms, including the *Indian Journal of Traditional Knowledge,* and civil society organizations, such as the Society for the Promotion of Himalayan Indigenous Activities (SOPHIA), contribute to preserving and validating indigenous ecological knowledge, thereby bridging traditional wisdom with formal research and policy. Policies should promote diversified farming systems, organic and natural farming initiatives, value addition, and local market development. Strengthening Farmer-Producer Organisations (FPOs), improving storage and processing infrastructure, and linking agriculture with eco-tourism can further enhance livelihood sustainability.

Conclusion: Toward a Resilient Agricultural Future

Uttarakhand's hill agriculture is at a pivotal juncture. Climate change, outmigration, and ecological degradation present significant challenges, yet also offer opportunities to reconsider development strategies. The future of sustainable agriculture in the region depends on integrating tradition with scientific advancement. Farmers in Uttarakhand have demonstrated the feasibility of such integration through their daily practices and adaptive strategies. Recognizing, supporting, and scaling these hybrid systems can foster productive, resilient, culturally rooted, and environmentally sustainable agriculture. By valuing indigenous knowledge alongside scientific innovation, Uttarakhand can become a model for sustainable mountain agriculture in India and globally.

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Remodeling the Organizational Structure of Indian Council of Agricultural Research for Transformation of Agriculture towards *Vikshit* and *Atmanirbhar* Bharat

1.0 Introduction

Bharat or India, is a nation defined by its immense geographical, cultural, and ecological diversity, a reality that is fundamentally reflected in its agriculture (*Krishi*). This sector is not merely an economic activity but the backbone of the rural economy and a cultural mainstay. While common threads connect farming practices across the subcontinent, such as the cultivation of major staple crops, the rearing of common livestock (animals and birds), and the harvesting of aquatic resources (fishes), the true character of *Bharatiya* agriculture lies in its vast and intricate diversity. Every agroclimatic region possesses a unique set of specialized commodities and operates under a distinct spectrum of environmental and socioeconomic constraints.

1.1. The Challenge of Diversity and Constraints

The national agricultural landscape is a mosaic, where the challenges faced by a farmer in the fertile, alluvial plains of the Indo-Gangetic basin are fundamentally different from those encountered by a farmer in the arid zones of Rajasthan or the acidic, hilly terrains of the Northeast. This immense heterogeneity dictates that a one-size-fits-all approach to agricultural development and problem-solving is inherently inefficient and, often, counterproductive.

Across these regions, specific problems manifest in unique ways. Water scarcity, for instance, may be a problem of chronic drought in one area, while in another, it might relate to waterlogging or inefficient irrigation management. Similarly, soil health issues span a broad range, from severe acidity and alkalinity in particular belts to micronutrient deficiencies and low organic matter content elsewhere. The perpetual threats posed by diseases, pests, and invasive weeds are also highly varied and localized, with distinct biotypes and strains flourishing under specific climatic conditions. Moreover, the specific breeds of animals, poultry, and fish that thrive in one region are often genetically unsuited to the stresses of another. These localized challenges, whether relating to the genetic potential of a crop variety, the optimal feed for indigenous livestock, or the management of a region-specific pest outbreak, all demand focused, region-specific interventions.

1.2 The Vision for Region-Specific Research

To effectively harness the potential of India's diverse agricultural base and ensure sustainable, equitable growth, a pragmatic planning strategy is essential. This strategy must move beyond generalized national-level mandates and focus on establishing Agricultural Research centers or *Krishi Anusandhan Kendras* (KAKs) tailored to the needs of each distinct agroclimatic region under Indian Council of Agricultural Research (ICAR) or *Bharatiya Krishi Anusandhan Parishad* (BKAP). The primary function of these decentralized centers would be to serve as hubs of innovation and knowledge, intimately connected to the local farming communities. These proposed *Kendras* would be mandated to conduct intensive, region-specific research and cater to local farmers and the stakeholders' economy. This dedicated focus would enable scientists to rapidly develop and deploy improved, high-yielding, and climate-resilient varieties of local crops, enhance the productivity of indigenous livestock (animals and birds) and aquaculture (fishes), and evolve tailored management practices. Crucially, their work would focus on immediate and practical problem-solving. This includes developing site-specific solutions for pressing issues like breeding disease and pest-resistant crop lines adapted to the local ecology, devising efficient water management and harvesting techniques appropriate for the regional rainfall pattern, and formulating amelioration strategies to correct local soil constraints such as acidity and alkalinity. By operating at a hyperlocal level, these KAKs can ensure that research findings are directly relevant, immediately applicable, and maximize impact on farmer livelihoods and regional food security. This targeted approach is the cornerstone of building a resilient, prosperous, and truly decentralized Indian agricultural system.

2.0 The Role of the Indian Council of Agricultural Research

The Indian Council of Agricultural Research (ICAR) or *Bharatiya Krishi Anusandhan Parishad* (BKAP) manages a vast and layered research infrastructure that extends its influence across the entirety of the country's diverse agricultural landscape. This extensive network, while providing a national footprint, clearly illustrates how ICAR has spread its wings throughout the country, with its resources thinly spread across numerous specialized units.

The foundational structure of ICAR includes 4 Deemed Universities, 65 Research Institutes, 15 NRCs (National Research Centres), 6 National Bureaux, 13 Directorates/Project Directorates, and 11 Agricultural Technology Application Research Institutes (ATARIs). This massive base is further supported by a multitude of outreach and coordination projects.

2.1 The Extensive Fragmented Research Network

ICAR's operational model relies on a decentralized, subject-matter approach, which simultaneously ensures coverage and leads to resource dilution across its six research divisions: Crop Science, Horticulture, Natural Resource Management (NRM), Agricultural Engineering, Animal Science, and Fisheries Sciences.

A breakdown of the research units under the major divisions highlights this extensive but thinly spread distribution. The Crop Science Division has a massive reach, housing the flagship IARI (a Deemed University) alongside 27 national research institutes (RIs). Its coordination efforts are substantial, involving 19 All India Coordinated Research Projects (AICRPs), 6 All India Network Projects (AINPs), and 7 Other Networks. Similarly, the Horticulture Division is supported by 12 national RIs, 5 National Research Centers (NRCs), and 5 Directorates, which coordinate activities through 11 AICRPs and 1 AINP. The Natural Resource Management (NRM) Division manages 15 RIs dedicated to critical areas like soil and water, which are linked to the ground through 10 AICRPs, 3 AINPs, and 2 Other Projects. The Animal Science and Fisheries Sciences divisions also maintain their own networks of institutes, NRCs, directorates, and coordinating projects, further multiplying the points of resource distribution.

2.2 The Consequence of Thinly-Spread Resources

The sheer number of independent entities RI, NRCs, Directorates, and multiple coordinating mechanisms like AICRPs and AINPs spread geographically across India, means that ICAR's commitment to address the diverse needs of every agro-climatic zone comes at a cost:

- Financial Resources are Stretched: The available budget must be divided across an exceptionally high number of separate administrative and research units, limiting the critical mass of funding required for large-scale, cutting-edge infrastructure or sustained high-risk research at any single location.
- Manpower is distributed: Scientific talent is spread across numerous, smaller centers. While this ensures local expertise, it can make it challenging to consolidate the top talent needed to form large, interdisciplinary teams capable of tackling the most complex national agricultural challenges.
- Focus is Diffused: The necessity of managing dozens of different institutes and scores of coordinating projects can diffuse the national research focus, hindering the ability to prioritize and rapidly scale up singular, high-impact national missions.

In essence, ICAR's structure provides a testament to its wide-ranging commitment, resulting in a wide national reach but often a shallow depth of dedicated resources at any single point within its massive operational system. The categorization of agricultural research units within the ICAR system, specifically the distinction between a Research Institute (RI) and a National Research Centre (NRC), often appears arbitrary and complicated when viewed through the lens of regional commodity importance. While the official designation is typically based on a commodity's perceived national strategic value, this structure frequently leads to an uneven distribution of resources, resulting in certain regionally vital crops receiving disproportionately less support.

2.3 The Tiered Structure and Its Implications

The ICAR structure assigns different tiers of resources and autonomy based on the perceived national significance of a crop or subject area. Generally, an RI, such as the ICAR-Indian Institute of Rice Research (IIRR), is mandated for commodities of paramount national importance, offering a broad research scope. RIs possess significantly more physical facilities, a higher number of sanctioned scientific and technical personnel, greater financial autonomy, and extensive infrastructure, including research farms and advanced laboratories. In contrast, an NRC, like the ICAR-National Research Centre for Banana, typically has a more focused mandate, a smaller physical footprint, fewer human resources, and a lower operating budget.

2.4 Arbitrary Designation Versus Regional Reality

The seemingly arbitrary nature of these designations becomes clear when comparing a crop's national status with its regional impact:

- Rice vs. Banana: Rice is indisputably a national staple, justifying the establishment of a full-fledged national RI (IIRR) in Hyderabad. However, Banana, though classified as an NRC (at Tiruchirappalli), is arguably the single most important commercial fruit crop in several southern and eastern states. In regions like West Bengal, Kerala, Tamil Nadu, and Maharashtra, banana farming sustains millions of livelihoods. Limiting it to an NRC designation means that the fundamental research into disease resistance, high-density planting, and post-harvest technology crucial for these regions is conducted with fewer scientists and restricted funding compared to a full-fledged RI. This scarcity becomes a constraint on its commercial potential.

- Wheat vs. Groundnut: Wheat is a dominant national food security crop, naturally warranting an RI (ICAR-Indian Institute of Wheat and Barley Research). Conversely, groundnut is classified under an RI (ICAR-Indian Institute of Groundnut Research, Junagadh), reflecting its national importance as a major oilseed. However, smaller but regionally vital oilseeds may not fare as well. Consider Rapeseed-Mustard, a critical oilseed in Rajasthan, Uttar Pradesh, and Haryana. While it is covered by the ICAR-Indian Institute of Rapeseed and Mustard Research, the relative resource allocation is still based on the strategic priority dictated by New Delhi, not the immediate, intense needs of the specific regional economies where it dominates.
- Horticultural Examples (Potato vs. Litchi): Potato is a critical vegetable across India, justifying a major RI (ICAR-Central Potato Research Institute, Shimla) with regional stations across the plains. In stark contrast, a highly profitable, region-specific fruit like litchi, which is economically paramount in Bihar and Uttarakhand, is designated as an NRC. This limits the scale of basic research into challenges like fruit cracking, pest management, and post-harvest handling, despite litchi being the primary source of income for many farmers in Muzaffarpur, Bihar. A full-fledged RI would provide the necessary long-term, multi-disciplinary research depth that an NRC, by its nature, cannot sustain.

The Consequences of Skewed Resources - The structural disparity between an RI and an NRC means that commodities deemed 'secondary' at the national level, even if they are 'primary' at the regional or local level, suffer from:

- Limited Disease and Pest Management: An NRC's smaller team may struggle to respond rapidly to a major, complex regional outbreak, such as the Panama Wilt in bananas or the Litchi Mite, which can devastate an entire season's income.
- Slower Varietal Development: Developing and field-testing new, climate-resilient varieties takes decades. An NRC's constrained budget and personnel can slow this critical process, leaving farmers to rely on older, more vulnerable cultivars.
- Reduced Linkages: A smaller NRC typically has less infrastructure for robust extension activities and linking with local *Krishi Vigyan Kendras* (KVKs), thereby delaying the transfer of already-developed technologies to the farmer.

This system, though intended to rationalize resource allocation, often inadvertently perpetuates the marginalization of regionally crucial crops, reinforcing the need for the decentralized *Bharatiya Krishi Anusandhan Kendras* (BKAKs) proposed earlier, where resource allocation is driven by the commodity's local economic and ecological importance, not just its national strategic ranking.

The highly specialized and fragmented mandates of ICAR Research Institutes (RIs), while intended to ensure deep focus on specific commodities or disciplines, often result in significant functional overlap and undesirable duplication of research efforts. This structure creates inefficiencies where multiple institutes independently pursue similar objectives, particularly in the cross-cutting fields of biotechnology and stress management (biotic and abiotic), leading to a thin spread of expertise and redundant expenditure.

2.5 The Inevitability of Duplication

Research in modern agriculture is inherently multidisciplinary. A commodity-focused institute must address every aspect of its crop's life cycle and utilization, inevitably requiring expertise that overlaps with specialized 'discipline' institutes.

2.5.1 Commodity-Specific Versus Cross-Cutting Institutes - The core of the duplication arises when a commodity institute's mandate intersects with that of a cross-cutting resource or discipline institute:

- Rice Research and Stress Management: The ICAR-Indian Institute of Rice Research (IIRR) has a primary mandate to improve rice varieties. This inherently includes developing tolerance to drought (an abiotic stress) and resistance to diseases like bacterial blight (a biotic stress). Yet, ICAR also operates dedicated institutes like the ICAR-National Institute of Abiotic Stress Management (NIASM) and the ICAR-National Institute of Biotic Stress Management (NIBM). The IIRR's scientists must, by necessity, perform research on stress tolerance specific to rice, which duplicates the fundamental work being done by scientists at NIASM and NIBM on developing general stress mitigation strategies.
- The Case of Oilseeds and Natural Resources: The ICAR-Indian Institute of Oilseeds Research (IIOR) focuses on Groundnut, Sunflower, and Castor. A key research area for IIOR involves improving varieties for dryland or moisture-stressed environments. This research directly overlaps with the core mandate of the ICAR-Central Research Institute for Dryland Agriculture (CRIDA), which works on integrated farming systems, soil conservation, and crop improvement specific to drylands, including oilseed crops. Both these institutes use their limited resources to tackle the same problem, the dryland oilseed cultivation, leading to potential duplication and reduced synergy.

2.5.2 Duplication of Advanced Disciplines - The problem is most acute in high-cost, advanced technology domains like biotechnology:

- Commodity Institutes and Biotech R&D: Nearly every major commodity RI (Rice, Wheat, Pulses, Horticulture Institutes) must have their own Biotechnology/Molecular Biology units to support their breeding programs (e.g., marker-assisted selection, genetic transformation, gene editing). These units independently develop protocols, manage basic molecular/biotechnology lab equipment, and train personnel specific to their crop.
- Dedicated Biotech Institutes: Meanwhile, ICAR maintains specialized institutes focused solely on the technology, such as the ICAR-National Institute of Plant Biotechnology (NIPB). NIPB's mandate is to pioneer biotechnological tools and platforms for agricultural crops. While this sounds complementary, in practice, the commodity RIs often undertake transformation and gene expression studies internally to maintain control over their breeding lines, leading to redundant purchases of high-end equipment (like sequencers or biolistic guns) and replicated efforts in establishing genetic transformation protocols already available at NIPB. Similar is the fact for the ICAR-Indian Institute of Agricultural Biotechnology (IIAB).

2.5.3 Consequences of Overlapping Mandates - This organizational model, characterized by specialization in silos, incurs several costs:

- Inefficient Resource Utilization: The independent acquisition of expensive, specialized equipment (like high-throughput phenotyping platforms or next-generation sequencers) by multiple institutes represents a suboptimal use of limited public funds.
- Competition over Collaboration: Instead of establishing a clear division of labor (e.g., NIPB develops the tool, IIRR applies it), the mandates encourage competition for publishing breakthroughs and securing grants in the same scientific domain, reducing collaboration.
- Fragmented Expertise: By spreading scientists working on, for example, fungal genomics across an institute for rice, an institute for horticulture, and a dedicated NIBM, ICAR fails to consolidate a critical mass of expertise necessary to lead global-scale research in that specific field.

To truly optimize the national agricultural research system, there is a clear imperative to move from mandates that prioritize single commodities or disciplines in isolation toward a more integrated, matrix-based structure where core technology and resource institutes serve as shared, high-capacity platforms, thus eliminating wasteful duplication. The concentration of ICAR Research Institutes (RIs) in specific locations, driven by historical context or initial research focus, often leads to major agricultural regions feeling conspicuously deprived of dedicated, nearby research support. This geographic imbalance creates a significant gap between research output and on-the-ground needs, especially for high-production areas and regionally dominant commodities.

2.6 The Geographical Imbalance: Core Crops

The location of apex research bodies, particularly for nationally significant crops, fails to align with the decentralized reality of production across India, resulting in a perceived oversight of major regional contributors:

2.6.1 The Case of Rice - Rice is cultivated across almost all states, exemplifying this imbalance. The primary national institute is the ICAR-National Rice Research Institute (NRRI) in Cuttack (Odisha), complemented by the ICAR-Indian Institute of Rice Research (IIRR) in Hyderabad (Telangana/Andhra Pradesh). While these institutes serve large rice-growing belts, states that are major contributors feel underserved:

West Bengal (WB): WB is one of the largest rice-producing states, with diverse ecosystems (coastal, deltaic, and hilly) that demand unique varietal research for waterlogging, salinity, and local pest complexes. Farmers in WB must rely on technology developed hundreds of kilometers away in Cuttack or Hyderabad, which may not be perfectly suited to their local agroclimatic conditions.

Tamil Nadu (TN): TN's rice agriculture, especially in the Cauvery Delta, requires specialized research into water management for short-duration crops and specific pest strains prevalent in high-intensity cropping systems. The distance to existing RIs diminishes the effectiveness of immediate technology transfer and extension work crucial for high-production regions.

2.6.2 The Case of Sugarcane - Sugarcane research is similarly centralized, with the ICAR-Indian Institute of Sugarcane Research (IISR) in Lucknow (Uttar Pradesh) and the Sugarcane Breeding Institute (SBI) in Coimbatore (Tamil Nadu). This bifurcation often neglects the needs of intermediate yet crucial regions. For instance, the cane belt of Maharashtra and Karnataka, a high-yielding area, depends on research from either the North or the far South, necessitating extensive, often slow, regional testing to adapt varieties for its specific soil and climate.

2.7 Underserved Regional Powerhouses

The issue is even more pronounced for crops where the major research institute's location is far removed from the core production pockets, leaving regional powerhouses without focused local support.

2.7.1 Groundnut in Southern India - While the main institute, the ICAR-Indian Institute of Groundnut Research (IIGR), is located in Junagadh (Gujarat), the major groundnut cultivation regions in Southern India often feel neglected:

- Rayalaseema Region (Andhra Pradesh): Districts like Anantapur in this region are among the largest groundnut producers globally, characterized by extremely low and erratic rainfall and severe drought stress. The research needs here center on ultra-drought-tolerant and short-duration varieties.
- Kolar (Karnataka) and North Arcot (Tamil Nadu): These districts also account for significant groundnut cultivation under rainfed conditions. They require locally adapted varieties and pest management strategies. Relying on an institute in Gujarat, a thousand kilometers away, for solutions

to region-specific soil, drought, and pest challenges leads to slow response times and inappropriate technology dissemination.

2.7.2 Pulses and Regional Semi-Arid Zones - Pulses, vital for protein security, are researched by the ICAR-Indian Institute of Pulses Research (IIPR) in Kanpur (Uttar Pradesh). However, many of the largest pulse-growing areas are in the semi-arid central and western regions:

Maharashtra and Madhya Pradesh: These states are major producers of Tur (Pigeonpea) and Chickpea. The environmental challenges (e.g., Fusarium wilt disease, terminal drought) faced by their farmers are distinct from the alluvial plains of Uttar Pradesh. The distance to IIPR and the lack of a dedicated regional presence mean that the transfer of new, resistant varieties and climate-resilient farming techniques is delayed and less effective locally.

This persistent geographical mismatch between the location of specialized RIs and the actual centers of high-volume, regionally dominant agricultural production strongly supports the argument for establishing decentralized, agro-climatic-zone-specific research centers with a direct mandate to solve local constraints.

The concentration of All India Network Projects (AINPs) headquarters in Delhi, particularly within the ICAR-Indian Agricultural Research Institute (IARI) campus, represents another facet of the centralized nature of India's agricultural research planning. While the testing units of these AINPs are spread across the country, their central coordinating units (Headquarters) often reside in a region that is not the primary geographical center of the network's actual activity.

2.8 Centralization of AINP/AICRP Coordination

AINPs are crucial as they link research efforts across multiple locations, facilitating national collaboration on specific, focused challenges. Four of the six such AINPs under the Crop Science Division are located in New Delhi. However, placing the coordination hub in New Delhi, or an institute like IARI, creates an inherent disconnect:

Example 1: Crop Science Division - The All India Network Project on Pesticide Residues is a key example from the Crop Science Division.

- Headquarters Location: The coordinating unit is located at the ICAR-Indian Agricultural Research Institute (IARI), New Delhi.
- Activity Disconnect: The actual work of residue analysis, monitoring food safety, and developing safe pesticide protocols happens in the field and laboratories across major agricultural producing states (e.g., in Punjab, Gujarat, and the Southern states). These states face intense pressure from pesticide use due to high-intensity farming. Centralizing the project's coordination in Delhi, where large-scale, primary crop production is not the major regional activity, means the project's administration is physically far removed from the core field-level issues and regional regulatory pressure points.

Example 2: Horticulture Division - The All India Network Project on Onion and Garlic (a coordinating unit of an AICRP) provides an example from the Horticulture Division.

Headquarters Location: The coordination unit is hosted by the ICAR-Directorate of Onion and Garlic Research (DOGR) in Pune (Maharashtra).

Local Relevance: In this case, the headquarters is hosted in Maharashtra, which is a major production hub for both crops. This is an example where the location aligns logically with the commodity's regional importance, suggesting a more pragmatic approach than placing it solely in Delhi.

Further Examples of Centralized Network Coordination - The tendency to use a large, existing national institute, often IARI in Delhi or a few other central institutes, as the host for national network projects is widespread:

Network Project Type	Common Headquarters Location	Geographic/Activity Disconnect
All India Coordinated Research Project (AICRP) on Honey Bee and Pollinators	IARI, Pusa, New Delhi	Beekeeping activities are most intensive in states like Punjab, Haryana, Uttarakhand, and Bihar. Locating the headquarters at IARI, while administratively convenient, is distant from the major apiary zones and migratory beekeeping routes.
All India Network Project on Vertebrate Pest Management (VPM)	ICAR-National Centre for Integrated Pest Management (NCIPM), New Delhi	Vertebrate pests (like rodents and wild animals) cause crop damage that is highly localized and varies widely from arid to hilly ecosystems. The core research and field extension work required for VPM are decentralized, making the Delhi location primarily an administrative convenience rather than a field-based necessity.

The consistent use of established, non-field-specific locations like New Delhi (IARI/NCIPM) as the headquarters for these national networks further reinforces the view that administrative ease and centralized control often take precedence over the efficiency gained by locating the coordinating unit closest to the major production areas and field scientists who actually execute the multi-location trials. This contributes to the issue of research becoming thinly spread and less responsive to specific regional crises.

The functioning of All India Coordinated Research Projects (AICRPs), while fundamentally designed to facilitate multi-location testing and technology dissemination, is plagued by structural and administrative issues that render them often ineffective, redundant, and burdensome. These problems stem primarily from the system of dual control between the ICAR and the State Agricultural Universities (SAUs), leading to administrative bottlenecks and legal complications for the personnel involved.

2.9 The Inherent Redundancy and Overlapping Mandates

The very concept of an AICRP frequently creates redundant research efforts, particularly in states where the SAUs already possess robust, region-specific research programs. SAUs are autonomous institutions with a clear mandate to serve the specific agro-climatic needs of their states' farmers. Their research activities, therefore, cover all major local commodities and constraints, directly competing with the ICAR-funded AICRPs.

Example: Potato Research - The case of potato research perfectly illustrates this redundancy. The national apex body, the ICAR-Central Potato Research Institute (CPRI), located in Shimla, conducts basic and strategic research and has regional stations across the country. Simultaneously, the AICRP on Potato operates centers within various SAUs. These SAU centers are mandated by the AICRP to conduct multi-location trials (MLTs) and local breeding efforts. However, the host SAU often has its own Directorate of Research or dedicated potato research unit operating under the state government's mandate. The SAU's internal research objectives on developing local, early-maturing, or disease-resistant varieties for state farmers are largely identical to the local objectives of the AICRP center stationed on the same campus. This results in two sets of scientists, often using the same limited facilities and personnel pool, working on near-identical goals, creating a significant and unnecessary duplication of efforts. The local SAU could easily absorb the MLT component into its existing research program, making the separate AICRP structure highly redundant and wasteful of scientific manpower.

2.10 The Administrative Burden and Dual Control

The administrative mechanism of the AICRPs is characterized by dual control, which creates friction and inefficiency. ICAR provides the research funding, sets the national objectives, and dictates the technical program. The SAUs, however, host the projects, provide the land, infrastructure, and manage the personnel.

2.10.1 Financial and Operational Disconnect - This setup creates a perpetual state of administrative tension:

Delayed Release of Funds: ICAR funds for the AICRP centers are often released to the SAUs with delays. Since the SAU budgets are already tightly managed, any delay in the release of central funds can severely hamper the timely execution of the research program, including the purchase of essential supplies or the conduct of seasonal field trials, ultimately compromising the quality of the scientific output.

Lack of Ownership: The AICRP scientists are often viewed as ICAR staff by the SAU administration, and the SAU administration's priorities are usually given precedence. The AICRP staff, in turn, feels answerable primarily to the ICAR Project Coordinator, creating a reporting ambiguity. This dual accountability slows decision-making, especially concerning resource utilization and personnel management. The SAU treats the AICRP as an additional burden rather than an integral part of its research mandate.

2.10.2 Legal and Ethical Complications for Personnel - Perhaps the most significant consequence of the dual-control structure is the legal and ethical discrimination faced by the scientists and staff working under the AICRPs.

2.10.3 The Pension and Service Discrimination - The employees of AICRPs are theoretically on par with their SAU counterparts, often holding inter-transferable positions equivalent to those in the university departments and directorates. However, in practice, discrimination emerges in retirement benefits, creating severe legal complications.

Pension Parity Breakdown: In some states, such as West Bengal, disturbing discrimination has emerged where the state government is reportedly not paying the pension of the scientists and staff working in the AICRPs, despite these scientists dedicating their entire careers to service on the SAU campus. Since the SAUs are largely managed by state governments, they are responsible for the pension liabilities of their regular employees. The AICRP staff, despite their equivalent positions, are sometimes treated as a separate category, leading to financial insecurity upon retirement.

Legal Complicacies: This administrative discrimination has forced aggrieved scientists to seek redress through legal channels. The irony is that the same administrative system that ensures inter-transferability of scientists between an AICRP center and a university department, implying parity in duties, qualifications, and responsibilities, simultaneously denies parity in retirement benefits. This lack of a clear, unified service structure for AICRP staff across the nation continues to generate a large volume of litigation, draining the time and resources of both ICAR and the SAUs, and severely demotivating the dedicated scientific workforce.

In conclusion, the AICRP structure, while theoretically a good model for multi-location testing, is practically ineffective due to a complex web of administrative inertia, dual control leading to financial delays and redundancy, and systemic discrimination against its personnel. This fragmented and legally complicated arrangement highlights the failure of centralized planning to harmonize research goals with the on-ground needs and administrative realities of state-level institutions.

2.11 Rationale for Change in Organizational Structure

The preceding analysis of the ICAR structure, revealing thinly spread resources, centralized control, arbitrary institutional mandates, and administrative friction within the AICRPs, makes a powerful case for a fundamental restructuring of the national agricultural research system. The core imperative is to decentralize the research focus and streamline the extension machinery to align with the diverse ecological and socioeconomic realities of the country. This systemic overhaul demands the creation of dedicated, region-centric *Krishi Anusandhan Kendras* (KAKs) and a complete devolution of the *Krishi Vigyan Kendra* (KVK) system to the SAUs. The complexity, lack of cohesiveness, and multiple challenges within India's National Agricultural Research System (NARS), primarily steered by the ICAR and the SAUs, necessitate a critical review that often points towards the need for reforms and/or restructuring. This assessment must be informed by successful global models.

2.12 Reforms Versus Restructuring National Agricultural Research System

The distinction between 'reform' and 'restructuring' is crucial in the Indian context of Agricultural Research in India.

- Reforms: Generally refer to institutional changes transforming the rules, norms, and incentives that govern the system. Examples include changes to research priority-setting processes, improving the scientific interface, providing greater functional autonomy to scientists, or revising funding mechanisms (e.g., competitive grants). India has a history of implementing reforms based on various committee recommendations (e.g., Gajendra Gadkar, Johl, and Mashelkar Committees), focusing on improving efficiency and responsiveness.
- Restructuring: Typically involves organizational changes altering the structure, mandate, and alignment of the existing entities (ICAR institutes, SAUs, extension wings). This could involve merging, decentralizing, or re-engineering administrative and functional units to improve collaboration and reduce redundancy. The World Bank-supported National Agricultural Innovation Project (NAIP) for India, for instance, had a strong restructuring component aimed at transforming the agricultural sector towards a market orientation.

In reality, for a system as large and complex as India's NARS, the path forward often requires a combination of institutional reforms and organizational restructuring to achieve meaningful and sustainable transformation.

2.12.1 Key Challenges in India's NARS Driving the Need for Change - The existing structure faces several challenges that necessitate both types of changes:

- Fragmented Linkages: There is often a weak link between research, extension, and farmers, as well as between central ICAR institutions and state-level SAUs, leading to inefficiencies in technology transfer and adoption.
- Focus Shift: The NARS, while historically successful in achieving food self-sufficiency (the Green Revolution), now needs to shift its focus towards sustainability, climate resilience, nutritional security, and enhancing farmers' income (moving beyond just production increases).
- Low Private Sector Engagement: The mechanism for collaboration and commercialization of technologies developed by public research institutions is often bureaucratic, hindering private sector investment and scaling of innovations. Agrinnovate India Ltd. was established to address this, but challenges remain.
- Governance and Autonomy: Issues related to administrative complexities, lack of functional autonomy for scientists in research matters, and slow decision-making processes can stifle innovation and research excellence.
- Addressing Regional Disparities: The research output and impact are often uneven, with a need to focus more on rainfed areas, small and marginal farmers, and lagging regions like Eastern India.

2.12.2 Reform or Restructuring: That is the question - The question in India is not an "either/or" choice between reforms and restructuring, but rather how to strategically implement both.

- Institutional Reforms (Rules & Incentives): Essential for changing the culture of research, promoting accountability, rewarding innovation, and improving the interface with the private sector and farmers.
- Organizational Restructuring (Structure & Alignment): Necessary to simplify the mammoth bureaucracy, ensure independence of SAUs and better coordination between ICAR and SAUs, and decentralize decision-making to make research locally relevant and responsive to varied agro-ecological zones.

The complexity, lack of cohesiveness, and multiple challenges within India's National Agricultural Research System (NARS), primarily steered by the ICAR and the SAUs, necessitate a critical review that often points towards the need for reforms and/or restructuring. This assessment must be informed by successful global models.

3.0 Successful Global Organizational Models and Their Merits

A review of the organizational structures of the countries leading in agricultural research, such as the USA, Canada, France, Italy, the Netherlands, Israel, Australia, Brazil, etc., will reveal a strong emphasis on regional centers and sub-centers rather than commodity, resource, constraint, or trait-wise centers. Organizational structure and its key merits of a few leading countries are briefed below, followed by a depiction of the USDA as the most successful model.

3.1. USDA (United States Department of Agriculture) - U.S.A.

The USDA's research is primarily executed by the Agricultural Research Service (ARS), which is the principal in-house research agency. ARS operates under the Research, Education, and Economics (REE) mission area. Its work is centrally coordinated across a vast network of research centers but strategically guided by a focus on four National Program (NP) Areas: Nutrition, Food Safety, Animal Production, and Natural Resources. This ensures that federal research addresses issues of national importance.

Key Merits:

- High Scientific Rigor and Strategic Focus: The direct governmental mandate ensures research focuses on long-term, high-risk strategic areas that the private sector might neglect, such as fundamental genetic research, germplasm resource conservation and management, and complex disease prevention.
- Integrated Policy Analysis: The REE mission area also includes the Economic Research Service (ERS), which provides independent, rigorous policy analysis and economic data. This integration allows the research agenda to be directly informed by market forces, trade dynamics, and economic impact studies.
- Scale and Infrastructure: Its centralized funding model maintains a vast, robust infrastructure, including the National Agricultural Library (NAL) and extensive field research centers, ensuring national coverage and standardized scientific excellence.

3.2. INRAE (National Research Institute for Agriculture, Food and Environment) - France

INRAE was created in 2020 through the merger of INRA (agricultural research) and IRSTEA (environmental research and technology). This organizational consolidation created a single, powerful public research institution focused on the triad of agriculture, food, and the environment. It is structured into scientific divisions (like Agroecology and Bioeconomy) and operates through 18 research centers across France, deliberately fostering multi-disciplinary research.

Key Merits:

- Holistic and Integrated Approach: The merger defines success, allowing INRAE to address modern challenges such as climate change and biodiversity loss holistically, linking farm productivity directly to environmental sustainability and public health. This is crucial for India, where sustainability is a top priority.
- Direct Policy Support: INRAE is explicitly mandated to produce knowledge to support public policies and inform national and European strategies. This close link ensures that research outputs are highly relevant to societal transitions and political decision-making.
- Promoting Interdisciplinarity: By combining institutes previously focused on separate domains (agriculture vs. environment), the structure inherently promotes cross-domain collaboration to solve complex systemic problems like water management or land-use change.

3.3. AAFC (Agriculture and Agri-Food Canada) - Canada

AAFC is a federal department responsible for providing leadership, policies, and programs for the Canadian agriculture and agri-food sector. Unlike a purely research agency, AAFC integrates research directly into its departmental mandate. It maintains a network of research and development centers across Canada, with research efforts strategically aligned with national priorities like enhancing environmental performance and strengthening the value chain.

Key Merits:

- Strong Industry-Research Linkage: AAFC excels at connecting its in-house science to market needs through programs like the AgriScience Program. This structure offers public funding and scientific support to businesses for pre-commercial R&D, effectively lowering the risk for private investment and accelerating commercialization.
- Targeted Innovation for Value Chains: By focusing on strategic objectives, AAFC ensures research is not just about production but also about improving the attributes for food and non-food uses and

addressing threats to the entire agricultural value chain (from farm to consumer).

- Regional Responsiveness: Maintaining various regional research centers ensures that R&D is tailored to the specific agro-climatic variations and commodity specializations across Canada, demonstrating a model for managing a large, diverse geography.

3.4. ARO (Agricultural Research Organization - Volcani Institute) - Israel

The ARO, known as the Volcani Institute, is Israel's national R&D center, operating as a governmental organization under the Ministry of Agriculture. It is a highly mission-oriented entity organized into specialized institutes (e.g., Plant Sciences, Soil, Water and Environmental Sciences, Agricultural Engineering) across three regional campuses. A notable feature is Kidum, a dedicated unit for commercialization.

Key Merits:

- Applied, Problem-Solving Focus: The ARO's core mandate is to focus intensely on applied research to address concrete challenges, particularly water scarcity and arid zone agriculture. This singular focus has driven world-leading innovations in drip irrigation, protected cultivation, and resource efficiency.
- Rapid Technology Transfer: The presence of Kidum ensures a dedicated, professional pathway for taking research findings from the lab to the market. This mechanism bypasses bureaucratic hurdles often found in purely governmental organizations, enabling rapid commercialization and farmer adoption.
- Multi-disciplinary Concentration: The concentration of six highly specialized institutes in three main centers fosters multi-disciplinary collaboration to solve specific problems (e.g., integrating water science, plant protection, and engineering for a single solution).

3.5. EMBRAPA (Brazilian Agricultural Research Corporation) - Brazil

EMBRAPA is a unique public, state-owned research company operating with a corporate management style. It manages a highly decentralized structure of over 40 research units. Crucially, these units are structured on a dual basis:

- Product/Commodity Units (e.g., Beef Cattle, Soybeans)
- Eco-regional/Thematic Units (e.g., Arid Zones, Forestry)

This structure, combined with strong strategic planning (Agropensa) and international presence (LABEX), has been instrumental in transforming Brazil's agriculture.

Key Merits:

- Decentralized Responsiveness and Local Adaptation: The dual structure allows EMBRAPA to simultaneously address national commodity needs and highly specific local ecological requirements. This model is highly relevant for India's diverse agro-ecological zones.
- Corporate Management Efficiency: Operating as a corporation allows EMBRAPA to adopt professional R&D management practices, including robust strategic planning, performance-based evaluation, and flexible resource allocation, often lacking in traditional government departments.
- Global Reach and Knowledge Sharing: Through its international offices (LABEX), EMBRAPA places its scientists in research centers of excellence worldwide, enabling constant interaction with global science and the rapid importation of cutting-edge knowledge.

3.6. Commonwealth Scientific and Industrial

Research Organization (CSIRO) - Australia

CSIRO is Australia's national science agency, mandated with meeting the country's most pressing problems using science and technology innovation. The objective of CSIRO is to conduct scientific research to benefit Australian industry, develop the interests of the Australian community, and contribute to national goals and international obligations. Its research is multidisciplinary and impact-oriented, addressing significant problems in a variety of sectors. CSIRO's research portfolio includes areas of Agriculture and Food, Health and Biosecurity, Energy, Manufacturing, Mineral Resources, Environment, and Digital and Data. There are over 50 locations of CSIRO in Australia, and it communicates research through an array of Business Units and has National Research Facilities and Scientific Collections in trust for the country.

Key Merits:

- Enhancing Crop and Livestock Performance Using Genetics and Breeding: CSIRO is a world leader in developing high-performing, disease-resistant crop varieties and livestock breeds for the unique and severe Australian climate. This includes developing disease-resistant crops (like cereal rusts) and breeding varieties that improve yield and require less water and fewer chemicals. One of the best examples is CSIRO's cotton breeding program, which backs 100% of Australian cotton and has led to a dramatic reduction in pesticide and herbicide use.
- Pioneering Digital Farming and Smart Agriculture Systems: CSIRO empowers farmers with advanced digital technologies and precision agriculture systems to reduce risk and optimize output. Its research in digital platforms, remote sensing, and data analysis, such as the Graincast yield forecasting app and WaterWise technology, enables farmers to make better decisions on water use, fertilizer, and pest control, which are crucial for drought resilience and responsible resource utilization.
- Driving Sustainability and Reducing Greenhouse Gas Emissions (Farm to Plate): CSIRO responds to major environmental problems by researching sustainable production of food and fiber. One of its greatest strengths is that it developed the feed supplement FutureFeed, which can reduce methane emissions in cattle by over 80%, offering a powerful instrument for the livestock industry to help counter climate change. It works on soil condition and water management, and also ensures the long-term sustainability and environmental footprint of Australian agriculture.

3.7. Synthesis for Indian NARS Transformation

For India's NARS, the path forward must strategically integrate the merits of these global models:

- Organizational Restructuring (The EMBRAPA Model): Restructure ICAR and SAU units to adopt a dual mandate, focusing on both major commodities/value chains and critical eco-regional challenges (e.g., arid zone agriculture, hill farming). This addresses fragmentation and ensures local relevance.
- Institutional Reforms (The ARO/AAFC Model): Implement radical reforms in IP management and create dedicated, professionally managed technology transfer units (like Kidum) with clear performance metrics to accelerate commercialization and private sector investment.
- Strategic Focus and Policy Linkage (The USDA/INRAE Model): Strengthen the economic research and policy analysis wings of the NARS to ensure that research priorities are rigorously determined by economic impact, sustainability metrics, and farmer income potential, moving beyond mere production targets.
- Autonomy and Accountability (ARC/Corporate Model): Grant greater functional autonomy to institutes and scientists to pursue innovation, balanced by a clear system of accountability based on measurable outcomes for farmers and the nation.

France's INRAE, Canada's AAFC, Israel's ARO, Brazil's EMBRAPA, and Australia's CSIRO reveal overarching lessons to transform the ICAR to achieve step-change advances in research productivity, farmer responsiveness, inclusivity, and global competitiveness. Despite possessing an unprecedented spread network of 731 Krishi Vigyan Kendras in every district, ICAR is facing issues such as poor R&D expenditure (lower than China's), project replication across institutions, outdated infrastructure, and limited competitive funding devices compared to the global arena. To address these constraints, ICAR needs to implement five disruptive pillars of international best practices: (i) Governance Reform inspired by INRAE's matrix structure linking 18 regional centers with 14 thematic divisions and AAFC's mission-based structure around grand challenges rather than disciplinary silos. (ii) Funding Modernization inspired by AAFC's competitive AgriScience program with outcome-based funding allocation and CSIRO's Rural Research and Development Corporations model enabling co-investment by the industry and the government; (iii) Strategic Focus replicating CSIRO's Ag2050 mission-based strategy for long-term transformation and EMBRAPA's ecology-based priorities that transformed Brazil's Cerrado savanna into a productive agricultural region; (iv) Regional Decentralization inspired by EMBRAPA's 46 state-dispersed, biome-specific centers and AAFC's federal-provincial cost-sharing mechanism with 60-40% partnership allowing local priority setting; and (v) Innovation Ecosystem Development inspired by ARO's applied R&D model with strong farmer-scientist collaboration and USDA's SBIR program for agritech startups and public-private partnerships. By synergizing these international frameworks with ICAR's existing excellence in extension delivery and disciplinary research, India can achieve its Viksit Bharat vision for climate-resilient agricultural development, doubling of farmers' incomes, and rural prosperity while making ICAR a competitive global research system that successfully translates laboratory innovations to farmers' fields at scale.

The change framework for ICAR can affect the integration of these five pillars through a managed implementation process to attain key outcomes such as increased research effectiveness by quality and impact measures, improved responsiveness among farmers through enhanced KVK mechanisms, increased inclusivity that guarantees equity and access to marginalized groups, and increased global competitiveness reflected in publications and global linkages. This collective approach acknowledges existing institutional challenges, like decreasing bureaucratic inefficiency, increasing lab-to-land connections, elevating public-private partnership, and promoting increased competitive research grants, while harnessing ICAR's own advantages of pan-India coverage, agricultural university networks, and ground-level extension infrastructure to create a next-generation agriculture research system in the service of India's vision for sustainable development.

3.8 The USDA Model - Structure, Function, and Strategic Approaches

The United States Department of Agriculture (USDA) is one of the 15 executive departments of the U.S. federal government that plays a foundational and dynamic role across the nation’s agricultural landscape. It is charged with overseeing as broad a set of sectors as food production, nutrition, rural economic well-being, environmental stewardship, and agricultural science at the direction of the Secretary of Agriculture, a Cabinet member appointed by the US President. The agency is organized into undertaking areas with various agencies and offices (Fig. 1), and its goals include addressing climate-resilient crops, promoting equity, strengthening the agricultural economy, and making nutritious food accessible to all Americans while judiciously conserving natural resources for future generations.

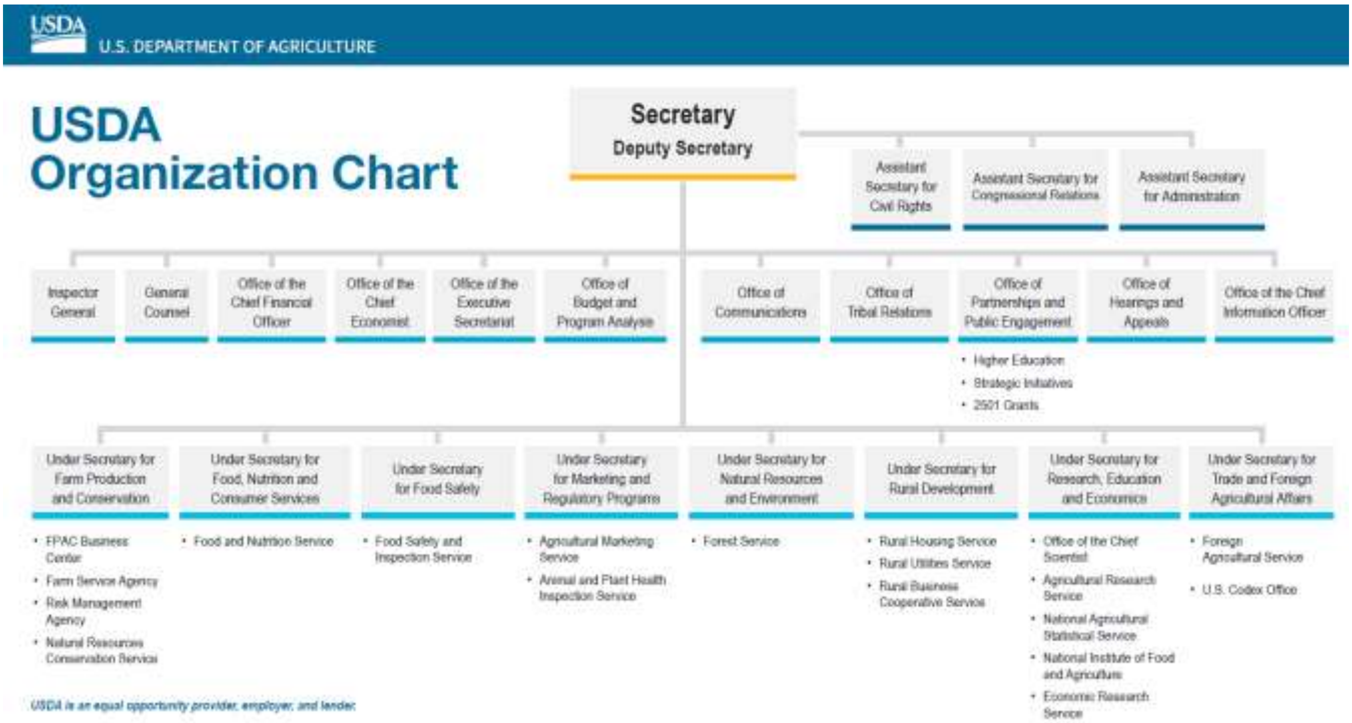


Figure 1: USDA organization chart and working agencies. *Source: USDA.gov*

3.8.1 Organizational Function and Structure - The depth and scope of the USDA are found in its structure, comprised of 29 agencies that are organized into eight mission areas (Fig. 2), which collectively contain the federal government's multi-faceted investment in American agriculture. Each mission area tackles specialized issues:

- *Farm Production and Conservation* guards the center of farm programs, reaching directly into American agriculture through such programs as crop insurance and disaster relief.
- *Food, Nutrition, and Consumer Services* oversees the nation's most significant nutrition safety nets, such as SNAP (Supplemental Nutrition Assistance Program) and WIC (Women, Infants, and Children program), ensuring that vulnerable groups have ongoing access to nutritional food.
- *Food Safety* is responsible for the safety of meat, poultry, and eggs by way of the Food Safety and Inspection Service (FSIS), helping to protect public health and food system reliability.
- *Marketing and Regulatory Programs* support fair marketing practices and competition, regulating commodity markets and upholding animal and plant health standards.
- *Natural Resources and Environment* supports conservation through the Forest Service and Natural Resources Conservation Service (NRCS) by facilitating programs related to soil health, water quality, forestry, and habitat conservation.
- *Research, Education, and Economics (REE)* propels agricultural advance through intramural and extramural research, conducted by the Agricultural Research Service (ARS) and National Institute of Food and Agriculture (NIFA), and by supporting the economic analysis necessary to evidence-based policy.

Figure 2: USDA mission areas range from direct aid to global trade.

- *Rural Development* focuses on developing prosperous rural communities, investing in infrastructure, housing, economic opportunity, and business innovation.
- *Trade and Foreign Agricultural Affairs* fosters U.S. farmers' and agribusinesses' competitiveness in the global arena, coordinating trade relations, exports, and international arrangements.

With approximately 100,000 employees divided among 4,500 office locations, the USDA reaches further and responds more by managing a network of mission-oriented agencies. Each of these agencies is headed by a Senate-approved Under Secretary, thereby ensuring accountability and strategic vision. Central specialty components, such as the Animal and Plant Health Inspection Service (APHIS), safeguard agricultural biosecurity, and the Office of Homeland Security offers readiness in case of agricultural disasters and emergencies.

3.8.2 Mission, Vision, and Strategic Priorities - The USDA's mission is inherent in every activity it undertakes, leadership in food, agriculture, natural resources, rural development, and nutrition on the soundest scientific principles and evidence available, and principles of good management. Its vision springs from this mandate, emphasizing shaping constructively the transition towards a more sustainable, adaptive, and equitable agricultural and food system. The USDA is guided by core values that include respect and dignity, equity and inclusion, trust and integrity, service and results, and science leadership.

The Department has set out five strategic pillars:

- *Food and nutrition security*: Sustaining national access to nutritious, safe, and affordable food.
- *Climate-smart agriculture and renewable energy*: Promoting greenhouse gas reduction, resilience, and transitioning to renewable energy in agriculture.
- *Fair and competitive markets*: Ensuring transparency, equity, and opportunity for all agricultural producers, regardless of size or background.
- *Equity and inclusion*: Offering support to historically disadvantaged and minority groups in

agriculture with a vision for systemic redress and common prosperity.

- *Biosecurity and resilience*: Protecting farms and the nation's food supply chain from pests, disease, and biothreats and strengthening the ability to absorb shocks.

This blend of sustainability, innovation, and inclusive access responds to the USDA's heritage as "The People's Department.".

3.8.3 State-Level Priorities and Programs - In supporting national objectives, the USDA recognizes the enormous diversity of America's farmland and challenges. Its state and local offices, predominantly the NRCS and Farm Service Agency (FSA), are empowered to modify federal program delivery consistent with regional and state-level priorities. By means such as the NRCS's "state ranking pool system," the states determine their top environmental or agricultural problems, such as soil and water conservation, drought control, restoration of habitats, or pest management, and direct federal money towards them. These localized programs demonstrate the Department's capacity for balancing federal guidance with knowledge and sensitivity at the local level so that programs can be responsive to both national policy needs and local needs.

3.8.4 Structure of Funding and Outcomes - The fiscal impact of the USDA is significant, with an approximate $467 billion per year being allocated through congressional appropriations, user fees, and international partnerships. The Farm Bill, which is renewed every five years, is the primary legislative vehicle that directs most of its funding, supplemented by bills like the Inflation Reduction Act and targeted initiatives like the Environmental Quality Incentive Program (EQIP) and Conservation Stewardship Program (CSP). In the last several years, USDA spent $2 billion with a particular charge to overcome a history of discrimination against minority producers, demonstrating its ongoing commitment to equity. The Department funding flows directly to individual farmers in loans, insurance, conservation grants, and disaster aid, as well as funding R&D, cooperative extension, and industry-wide resilience. Increasingly, outcome-based performance is applied, linked to increases in yields, environmental stewardship, and access to wholesome food, thus promoting fiscal restraint and measurable progress.

3.8.5 Regulations - The regulatory power of the USDA is expensive and important, covering food safety and labeling, farm loan regulations, market management, and environmental conservation. Recent moves have targeted future priorities, such as the creation of the Greenhouse Gas Technical Assistance and Third-Party Verifier Program to help facilitate voluntary carbon markets, the revision of Packers and Stockyards competition regulations to achieve fairness, and the formulation of tough standards for emerging technologies such as cell-cultivated meat. NIFA, as the governing body of grants, has an official four-phase process: pre-award, award, post-award, and closeout, being prudent in all. The USDA enforces a wide range of regulations to ensure food safety, protect animal and plant health, and manage natural resources. These regulations cover areas such as: (a) *Animal Health Protection:* Laws like the Animal Health Protection Act restrict the movement of animals and products to prevent disease spread. (b) *Food and Drug Administration (FDA) Oversight:* In cooperation with the FDA, the USDA ensures the safety of the nation's food supply. (c) *Organic Standards:* The USDA amends organic regulations, such as prohibiting certain nonorganic ingredients in processed organic products.

3.8.6 Opportunities and Innovation - As a science and innovation leader, the USDA offers plenty of research fellowships, grants, and innovation challenges under ARS, NIFA, and others. Its Small Business Innovation Research (SBIR) and Technology Transfer Programs are focused on promoting cutting-edge agritech and start-ups. Opportunities are huge in areas like food biotechnology, digital agriculture, renewable fuels, and pandemic preparedness, with land-grant university collaborations ensuring a consistent pool of talent and field-ready solutions.

3.8.7 Comparison of USDA with ICAR - The ICAR is the country's leading institution for agricultural research, education, and extension. The ICAR is governed by the Ministry of Agriculture and Farmers Welfare and is responsible for a gigantic network of 113 research institutes dealing with crops, livestock, fisheries, and allied sciences. Like the USDA's Research, Education, and Economics mission area, ICAR unites its research and extension responsibilities in networks like the U.S. Cooperative Extension System, delivering regionally based technologies and information to Indian farmers.

ICAR has pioneered outstanding strides in precision breeding, climate-tolerant crop lines, bio-fortified foods, and animal health. It formulates technical innovations, builds human capacity, and delivers context-specific innovations through its KVKs, the world's largest grassroot outreach agricultural complex network, offering technology transfer and farmer education on a record scale.

<u>Remodeling ICAR with USDA Approaches</u> - ICAR's dynamism and viability for the future can be significantly enhanced by onboarding proven USDA models and approaches. Some key areas for adaptation are:

- *Mission-based organization:* Organizing ICAR divisions along broad themes like nutrition security, climate resilience, and market integration, and not just disciplinary silos, would create cross-sector solutions and combined outcomes.
- *Genetic Resource Network and Crop Resilience:* Inspired by the USDA-NP program, ICAR would establish National Genetic Resource Network Areas. This mission is crucial as it leverages India's two mega-biodiversity hotspots, the Western Ghats and Eastern Himalayas, to discover, conserve, and utilize unique native fauna and flora. By safeguarding these vast genetic resources, ICAR would develop new crop varieties with greater resilience, higher yields, and improved quality, directly ensuring a stable and abundant national food supply.
- *Data-driven governance:* The incorporation of USDA-style transparency, real-time assessment, and local priority-setting can allow for more targeted, measurable interventions, as well as enable policy harmony from the center to the state.
- *Combined, competitive funding:* A shift towards open, outcomes-based funding systems (like the USDA's AFRI and BRAG) would drive innovation and encourage effective research, driving rapid development in priority sectors.
- *Strong public-private partnerships:* Scaling the SBIR model to support agritech startups and encourage university-industry partnerships would induce entrepreneurship and research commercialization.
- *Climate-smart platforms:* Institutionalizing conventional greenhouse gas emission metrics and developing certified and market-ready carbon credit mechanisms would help India upscale climate action in agriculture along the lines of proven USDA practices.

USDA's policy-based, outcome-focused approach ensures cohesion between research, strategy, and local action, while ICAR's strength lies in its focused disciplinary research and massive knowledge network. USDA is a federal ministry with a governing-in-one-form integrated government, bridging regulation, research, and policy, while ICAR is India's scientific peak organization and is primarily involved in R&D coordination and capacity building. Strengthening ICAR's state-level autonomy, using outcome-based competitive research funding, and using USDA-style outcome-based measurement could enhance India's agricultural innovation effectiveness and policy alignment. Blending product-based management, flexible local implementation, and integrated funding systems from the USDA with ICAR's research capacity would drive India's agricultural innovation and resiliency. By adopting and indigenizing these frameworks, ICAR can make a significant step change in research effectiveness, farmer responsiveness, inclusivity, and global competitiveness, thereby promoting India's aspirations for sustainable agricultural development and rural well-being (Fig. 3).

Figure 3: Transforming ICAR for global competitiveness.

4.0 The Suggested Model for India

A Policy Proposal for *Krishi Anusandhan Kendras* (KAKs) under the *Bharatiya Krishi Anusandhan Parishad* (BKAP) - This policy proposal outlines a suggested model for establishing and operating KAKs throughout India. These centers would function under the umbrella of the proposed BKAP. The model aims to decentralize agricultural research, ensuring it is regionally relevant, farmer-centric, and swiftly translates innovations from lab to field to boost productivity and sustainability across the diverse agro-climatic zones of the nation.

4.1 The Design Principles

4.1.1 Tiered and Simple Structure

• National KAK (BKAP HQ): National coordination, standards, national R&D priorities, large analytics and data platform, policy liaison.

• Zonal KAKs (15 nos.): One KAK per erstwhile NARP agro-climatic region to ensure simplicity (clear geographic coverage) and manageable scale for coordination.

• Sub-regional/State Hubs: Clustered KAK satellite units or partnerships at ICAR institutes serving NARP sub-zones (NARP has many subzones ~127). These manage local trials, demonstrations, and extension outreach.

• Mobile KAK Units / Digital KAK Services: For islands, remote highlands, and very isolated pockets to ensure equality of access.

4.1.2 Equality-by-design

• Equal baseline service standard for each zonal KAK: Minimum staff, mobile outreach capacity, demonstration farms, climate advisory desk, seed/inputs lab, and farmer training resources.

• Resource Allocation Formula Combining (a) Agricultural population served, (b) Cropping diversity/vulnerability index, (c) Poverty & smallholder density, and (d) Ecological fragility - to avoid "one-size-fits-most" and ensure disadvantaged zones get proportionally more support.

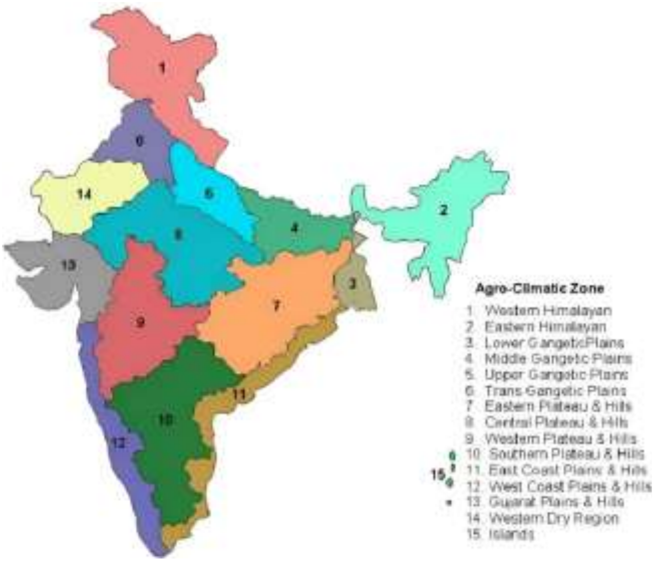
4.1.3 Simplicity in Governance

• Single point of contact per KAK (Zonal Director) reporting to BKAP National KAK with standardized reporting templates and a shared digital dashboard (National → Zonal → State).

- Standard operating procedures (SOPs) for research-to-extension pathways, technology validation cycles, and farmer feedback loops.
- Local Adaptation with centralized support.
- Zonal KAKs focus on location-specific R&D and varietal/advisory validation while leveraging National KAK for big data, model development, and national policy research.

4.2 The Proposed Zonal Network

This policy proposal outlines a suggested model for establishing and operating the KAKs throughout India. These centers would function under the umbrella of the proposed BKAP. The model aims to decentralize agricultural research, ensuring it is regionally relevant, farmer-centric, and swiftly translates innovations from lab to field to boost productivity and sustainability across the diverse agro-climatic zones of the nation. India consists of 15 major climatic zones as depicted in Figure 4. The description of the 15 agro-climatic regions should have one KAK established in a convenient city in one of the States or in a Union Territory, as indicated with geographical coordinates as given in Table 1.



Source: IAS.gov

Figure 4: Major Agro-climatic zones in India.

4.3 Operational / Functional Design

The following three terms describe a crucial, coordinated process in agricultural research and development, particularly those to be undertaken by institutions like KAKs, to tailor scientific innovations to a specific geographical area.

4.3.1 Crop and System Research Unit - The suggested mandate for the unit is as follows:

1. Varietal Trials - Varietal trials are the first and most fundamental step after a new crop variety (e.g., a new type of high-yield wheat or drought-resistant rice) has been developed in a centralized research lab or breeding program. They involve rigorously testing multiple candidate varieties under a set of standardized conditions across several different locations within a defined agro-climatic zone.

- Purpose: To compare the yield, quality, disease/pest resistance, and maturity period of new varieties against the currently popular, established (local check) varieties. Outcome: Identifying a few "best-fit" varieties that show superior performance and stability under controlled field conditions.

2. Adaptive Trials - Adaptive trials follow varietal trials. They are conducted on a much smaller scale, often directly on farmers' fields rather than on controlled research stations. They test the already-identified best-fit varieties from the varietal trials under real-world, diverse farming conditions and management practices typical of the zone.

- Purpose: To assess how the new variety adapts to local soil types, water availability, microclimates, and actual farmer resource constraints. The focus is on acceptability and performance under local conditions, not just maximum yield potential.

NARP (NARP region name)	Proposed KAK (host city)	State/UT	Lat (N)	Long (E)
Western Himalayan Region	Palampur	Himachal Pradesh	32.11	76.54
Eastern Himalayan Region	Shillong	Meghalaya	25.58	91.89
Lower Gangetic Plain Region	Kolkata	West Bengal	22.57	88.36
Middle Gangetic Plain Region	Patna	Bihar	25.61	85.15
Upper Gangetic Plain Region	Lucknow	Uttar Pradesh	26.85	80.94
Trans-Gangetic Plain Region	Hisar	Haryana	29.15	75.72
Eastern Plateau & Hills Region	Ranchi	Jharkhand	23.34	85.29
Central Plateau & Hills Region	Nagpur	Maharashtra	21.14	79.08
Western Plateau & Hills Region	Indore	Madhya Pradesh	22.71	75.85
Southern Plateau & Hills Region	Hyderabad	Telangana	17.38	78.49
East Coast Plains & Hills Region	Visakhapatnam	Andhra Pradesh	17.68	83.21
West Coast Plains & Hills Region	Mangaluru	Karnataka	12.91	74.85
Gujarat Plains & Hills Region	Ahmedabad	Gujarat	23.02	72.57
Western Dry Region	Jodhpur	Rajasthan	26.26	73.00
Island Region	Port Blair	Andaman & Nicobar Is.	11.62	92.72

Table 1: List of Agro-climatic Zones and suggested locations for establishing KAKs.

Outcome: Final validation of the variety's potential and suitability before large-scale seed multiplication and release.

3. Integrated Crop Management (ICM) Suited to Zone - Integrated Crop Management (ICM) is a holistic, system-level approach that goes beyond just the variety. It is a set of best practices covering every aspect of the cropping cycle, specifically optimized (suited) for the unique environmental and socioeconomic conditions of a particular agro-climatic zone.

- Components: This includes recommended seed selection (the varieties validated by the trials), precise planting methods, customized fertilizer and irrigation schedules, and integrated pest and disease management (IPM) strategies.
- Purpose: To maximize yield and resource efficiency (water, nutrients) while minimizing environmental impact and production costs. The KAK's role is to develop and disseminate this complete ICM package, which incorporates the locally validated varieties and management techniques, ensuring sustainable and profitable agriculture for the local farming community.

4.3.2 Climate and Agrometeorology Desk - The Climate and Agrometeorology Desk within a KAK will act as the vital link between national meteorological agencies and local farmers. Its primary function is to transform complex weather data into site-specific, actionable agricultural advice to enhance farm resilience and productivity. The desk receives seasonal climate forecasts (e.g., predicted probabilities of 'below-normal,' 'normal,' or 'above-normal' monsoon rainfall) from sources like the India Meteorological Department (IMD). Its role is to downscale and contextualize this information for the KAK's specific agro-climatic zone. This translation involves relating the forecasted parameters (like total rainfall, temperature anomalies, and onset/withdrawal dates) to the performance of locally dominant crops and the vulnerability of local farming systems.

Risk Advisories - Based on the translated forecast, the desk issues risk advisories for farmers. For example:

- Forecast: High probability of late monsoon onset and mid-season dry spells.
- Advisory: Advise farmers to plant short-duration, drought-tolerant varieties (identified *via* the varietal trials) and adopt water-saving techniques like ridge-and-furrow planting.
- Conversely, if heavy rainfall is forecasted, advisories focus on drainage, pest/disease management, and timely harvesting. This proactive guidance helps farmers mitigate losses and adjust resource allocation.

Climate-Smart Cropping Calendars

- The desk develops Climate-Smart Cropping Calendars, which are dynamic, not static. While traditional calendars fix sowing and harvesting dates, the climate-smart version integrates the seasonal forecast to provide adaptive recommendations.
- Adjusted Sowing Dates: Recommending a delay or advancement in planting based on the predicted onset of the rainy season.
- Variety Selection: Matching the most suitable crop variety (short, medium, or long duration) to the expected season length and weather profile.
- Optimal Input Timing: Advising on the best timing for irrigation, fertilizer application, and plant protection measures to align with expected weather events, ensuring inputs are used efficiently and are not washed away by unseasonal rains. This ensures local agriculture remains sustainable and climate resilient.

4.3.3 The Soil and Water Laboratories - The Soil and Water Lab is the foundation of site-specific nutrient and water management within the KAK. Its activities are critical for moving away from generalized fertilizer applications toward precision farming tailored to the unique characteristics of the local region.

1. Soil Testing and Nutrient Prescription - The primary function is conducting comprehensive soil testing for local farmers. Analysis goes beyond the basic NPK (Nitrogen, Phosphorus, Potassium) to include 12 key parameters such as Organic Carbon (OC), pH, Electrical Conductivity (EC), and critical micronutrients Zinc, Iron, Copper, Magnesium, and Boron. Based on these results, the lab generates Soil Health Cards with crop-wise and dose-specific fertilizer recommendations. This eliminates blind application, improves fertilizer use efficiency, reduces environmental run-off, and ultimately lowers farmers' input costs while boosting yields.

2. Salinity and Alkalinity Management - The lab specializes in diagnosing and managing problematic soils, particularly those affected by salinity (high salt concentration) and alkalinity. Using the Electrical Conductivity readings, the desk advises farmers on appropriate reclamation measures. This includes recommending specific soil amendments like gypsum, promoting the use of salt-tolerant crop varieties, and advising on better drainage techniques to flush out excess salts, thereby restoring the productivity of degraded land.

3. Micro-Irrigation Advisory - Given India's water scarcity, the lab provides essential Micro-Irrigation Advisory services. This involves linking soil type, crop water requirements, and local water quality to recommend the most efficient irrigation system (drip, micro-sprinkler, or rain-gun). Advisories are centered on the principle of 'More Crop Per Drop,' offering.

- Irrigation Scheduling: Informing farmers when and how much to irrigate based on soil moisture and crop stage.
- Fertigation: Guiding dissolving fertilizers in the irrigation water for maximum nutrient uptake and minimal wastage. The lab essentially ensures that both soil health and water resources are managed sustainably at the local level.

4.3.4 The Plant Health and Seed Unit - The Plant Health and Seed Unit is pivotal in the KAK's mission, focusing on prophylactic crop protection and ensuring the availability of high-quality genetic material. This two-pronged approach safeguards crop yields from both biotic threats and poor seed quality.

1. Pest and Disease Rapid Diagnostics - This desk serves as a local Plant Clinic, equipped for the rapid diagnosis of emerging pest infestations and disease outbreaks.

- Surveillance: Scientists conduct regular field scouting and leverage technologies (like mobile apps and imaging) to monitor crops for initial signs of stress.
- Lab Analysis: When samples arrive, the unit utilizes simple, yet effective tools from microscopy to specialized test kits (e.g., Lateral Flow Assays for viruses) to identify the specific pathogen or pest (fungus, bacteria, virus, or insect).
- Actionable Advice: Crucially, rapid diagnosis allows for the immediate issuance of Integrated Pest Management (IPM) advisories, recommending precise, minimal use of chemicals only when necessary, or promoting biological control measures. This prevents widespread epidemic loss and reduces farmers' dependence on broad-spectrum pesticides.

2. Quality Seed Multiplication Linkages - The unit is instrumental in the seed production chain, ensuring that the superior, locally validated crop varieties reach the farmers quickly.

- Breeder Seed Link: It acts as the nodal point connecting National/State Research Institutions (suppliers of breeder seed) with local seed growers and Farmer Producer Organizations (FPOs).
- Foundation/Certified Seed Production: The unit oversees the multiplication process within the KAK's demonstration farm or through designated partners to produce Foundation and Certified seeds. This is done under strict quality control checks for genetic purity, physical quality, and seed health.
- Distribution: By establishing strong linkages with local FPOs and cooperatives, the KAK ensures the timely supply of disease-free, climate-smart seeds to farmers in the district, thereby maximizing the genetic potential of the crops grown in the zone and increasing the overall Seed Replacement Rate (SRR).

4.3.5 Extension and Capacity Building Unit - The Extension and Capacity Building Unit is the outreach and knowledge transfer arm of the center, ensuring that research findings and modern practices are effectively disseminated and adopted by the local farming community. Its mandate is to bridge the gap between lab and land.

1. Capacity Building and Demonstrations - The core activity is skill development and practical learning.

- Farmer’s Training: The unit organizes frequent, need-based training programs on all aspects of the farming value chain, from soil health management and pest control to post-harvest handling and value addition. These sessions focus on "learning by doing" to ensure practical skill transfer.
- Demonstration Plots: Frontline Demonstrations (FLDs) and On-Farm Testing (OFTs) are conducted directly on farmers ’fields. The FLDs highlight the production potential of proven technologies (e.g., new seed varieties, Integrated Nutrient Management) under real-world conditions, acting as a visible, convincing tool for faster adoption by neighboring farmers.

2. Digital Extension and Advisory Services - To achieve a broad and timely reach, the unit leverages Information and Communication Technology (ICT).

- IVR/SMS/Apps: It provides real-time advisories on weather, pest outbreaks, and market prices via digital platforms, including Interactive Voice Response (IVR) systems and dedicated mobile applications. This ensures critical, personalized information reaches even remote farmers quickly and at a lower cost than traditional methods.
- Knowledge Hub: The unit functions as a Knowledge and Resource Centre, offering expert advice through farm visits and helplines, making it a critical support system for day-to-day farming challenges.

3. Gender-Inclusive Programming - The unit specifically designs its programs to address the needs of women farmers, who constitute a massive portion of the agricultural workforce yet often face barriers to accessing information and resources.

- Targeted Training: Training is scheduled and located to accommodate women's roles and responsibilities, often focusing on areas where women have high participation, such as seed production, horticulture, and post-harvest value addition.
- Empowerment: By promoting the participation of women in Self-Help Groups (SHGs) and building their technical skills, the unit ensures that extension services are gender-responsive, ultimately leading to enhanced decision-making power and improved household food security.

4.3.6 Data and Monitoring Cell - The Data and Monitoring Cell is the central nervous system of the institution, responsible for transforming raw operational data into actionable insights for continuous improvement and accountability. It ensures that all activities are evidence-based and responsive to farmers' real needs.

1. Standardized Data Collection and Dashboards - The cell establishes standardized protocols for collecting data from all units, ensuring consistency in measuring inputs, outputs, and outcomes across all extension activities and research trials.

- Inputs Tracked: Training attendance, number of advisory calls, quantity of seed/planting material produced.
- Outputs/Outcomes Tracked: Adoption rates of modern technologies, yield increases in demonstration plots, farmer income growth, and pest/disease incidence reduction.

This comprehensive data is integrated into digital dashboards, providing a real-time, visual overview of the institution's performance against its key performance indicators (KPIs) and targets. This enables quick identification of successful interventions and areas needing corrective action.

2. Monitoring, Evaluation, and Accountability - The cell spearheads the Monitoring and Evaluation framework, moving beyond simple activity tracking to assess the impact of interventions.

- Monitoring is an ongoing check of project execution (e.g., are training sessions happening on schedule?).
- Evaluation is a periodic assessment of whether the programs are achieving their desired results (e.g., has the training on seed treatment led to a reduction in seed-borne diseases?). The Monitoring and Evaluation reports are critical for accountability to stakeholders and funding agencies.

3. Farmer Feedback Loop - A crucial function is institutionalizing the farmer feedback loop to ensure the service remains farmer-centric and relevant.

- Collection: Feedback is formally gathered through surveys, focus group discussions, post-training reviews, and analysis of help-line data (IVR/app queries).
- Analysis and Action: The collected feedback is analyzed to identify gaps, if farmers report difficulty in accessing a specific technology, or if an advisory is unclear. This analysis is immediately channeled

back to the respective technical and extension units to refine their programs and adjust content, ensuring that research and extension are continually aligned with farmers' ground realities and constraints.

4.3.7 Partnership and Outreach Unit – This Unit is the institutional arm responsible for forging crucial collaborations to amplify impact, leverage resources, and ensure the seamless flow of technology and inputs to the farming community.

1. Public Sector Linkages - The unit serves as a vital bridge connecting the center with the broader agricultural ecosystem.

- State Agriculture Departments (SADs): This is a critical link for convergence and scaling. The unit coordinates its on-farm trials and demonstrations with the state's schemes to ensure technologies adopted by farmers are financially supported by government programs. They jointly organize Kisan Melas (farmer fairs) and extension campaigns to maximize reach.
- State Agricultural Universities (SAUs) and ICAR Institutes: This link is crucial for technology sourcing and validation. The unit obtains Breeder and Foundation seed of newly released, high-yielding, and climate-resilient crop varieties from these research bodies. They also collaborate on joint research projects and draw upon subject-matter experts for specialized training and diagnostics.

2. Private Sector and Startup Engagement - To enhance service delivery and market access, the unit actively partners with non-public entities.

- Seed and Input Companies: Partnerships with established private sector companies ensure the timely and quality supply of certified seeds, fertilizers, and plant protection chemicals to farmers at fair prices. This collaboration often includes joint training programs to demonstrate the effective use of novel products.
- Agri-Startups and Tech Companies: The unit focuses on linking with innovative Agri-Tech startups that offer digital solutions. This includes integrating precision farming services, such as soil testing, drone-based spraying, or customized farm management apps/dashboards, into the extension mandate. These collaborations modernize extension delivery and connect farmers to next-generation tools, ensuring greater efficiency and resource optimization.

3. Outreach and Resource Mobilization - Beyond technology transfer, the unit engages in resource mobilization. By demonstrating impact, it builds trust with corporate entities for Corporate Social Responsibility (CSR) funding, mobilizing resources to scale up activities like infrastructure development, specialized machinery procurement, and large-scale farmer capacity building that would otherwise be beyond the direct budget.

4.4 Mission-Oriented Krishi KAKs under BKAP

The Mission-Oriented KAKs under BKAP will function as specialized research and innovation hubs focusing on region-specific challenges and opportunities in Indian agriculture. Each KAK will integrate germplasm conservation, varietal improvement, agrometeorological intelligence, and technology dissemination with a clear mission-driven framework.

4.4.1 Key Features - Germplasm Repositories: Germplasm Repositories are fundamentally important because they serve as biological insurance for the future of agriculture, providing the necessary genetic raw material to combat unforeseen threats like climate change, new virulent pests, and diseases. The vast and diverse genetic heritage contained within these banks, including climate-resilient crops and indigenous and underutilized varieties, holds traits for drought tolerance, heat resistance, and superior nutritional content that may be lost forever if not actively preserved. Their establishment is crucial for continuous varietal improvement and ensuring food security in the face of environmental volatility. The process of establishing these local and national gene banks starts with a comprehensive exploration and collection of plant genetic resources across the target agro-ecological zones, prioritizing wild relatives and landraces adapted to local stress conditions. This is followed by rigorous characterization and documentation, where each accession is thoroughly evaluated for its morphological, genetic, and performance traits, linking it to its precise geographical origin. The collected material then undergoes multiplication and purification to generate adequate seeds for long-term conservation, which is achieved by storing seeds under controlled, low-temperature, and low-humidity conditions. Finally, the repository must establish an efficient information management system and distribution mechanism to ensure that this invaluable genetic material is readily available to breeders, researchers, and local farming communities, effectively closing the loop between conservation and utilization.

4.4.2 The Mission of KAKs - The Mission-Oriented KAKs will organize their research and extension efforts around critical Mission Themes, directly addressing the most pressing, region-specific challenges to agricultural sustainability and profitability. These themes integrate scientific disciplines to deliver holistic solutions to farmers as discussed below.

- Soil Health Management: This mission focuses on moving beyond basic fertilizer applications to implement comprehensive precision nutrient management. Activities include detailed soil mapping, promoting the use of biofertilizers and organic amendments, and developing practices to enhance soil carbon sequestration and microbial biodiversity. The goal is to restore soil fertility and structure, ensuring the long-term productivity of the land.
- Water Use Efficiency (WUE): Recognizing water scarcity, this mission is dedicated to maximizing "more crop per drop." It involves assessing and promoting technologies like micro-irrigation (drip and sprinkler systems), popularizing drought-tolerant crop varieties, and refining irrigation scheduling through advanced sensors and weather data. This ensures efficient allocation of water resources for optimal yield.
- Crop-Weather Relationships and Climate-Smart Farming: This critical mission theme integrates agrometeorological intelligence into farming practice. KAKs will develop real-time weather-based agro-advisories for farmers, covering critical activities like sowing, spraying, and harvesting. The mission also focuses on promoting climate-smart farming (CSF) practices such as conservation tillage, crop diversification, and the use of short-duration, heat-tolerant crop varieties to mitigate the impact of unpredictable weather events.
- Bioresource Valorization: This theme addresses sustainability by finding value in agricultural byproducts. It focuses on the utilization of farm waste and crop residues to produce value-added items, such as compost, biogas, or livestock feed, instead of burning them. This not only tackles pollution but also creates circular economy opportunities for rural youth and women, boosting local entrepreneurial activities. The overall approach is to create a resilient, efficient, and profitable agricultural system within the region.

4.5 The Regional Relevance

The core principle guiding the mission-oriented KAKs is regional relevance, achieved by aligning each KAK's mandate with a specific erstwhile NARP agro-climatic zone. This strategic alignment ensures that research, innovation, and extension efforts are not generic but are instead precisely tailored to the unique environmental, soil, and socio-economic conditions of that zone.

4.5.1 Precision in Problem Solving - India's vast agricultural landscape is divided into distinct NARP zones based on factors like rainfall, soil type, temperature, and cropping patterns. A problem like salinity in a coastal zone requires a different solution than water stress in a semi-arid zone. By establishing a KAK within a specific NARP zone, the institution can:

- Focus Research: Dedicated scientists concentrate their efforts on the zone's top priorities, such as breeding salt-tolerant rice for coastal areas or developing drought-resilient millets for rainfed uplands. This avoids the wasteful pursuit of "one-size-fits-all" solutions.
- Validate Technology: All On-Farm Testing and Frontline Demonstrations are conducted under the precise environmental and farming system conditions of the zone. This step is critical because a technology that performs well in a lab or a different state may fail locally due to unique pests, soil nutrient deficiencies, or micro-climate variations.

4.5.2 Direct Local Benefit and Scaling - This hyper-localization ensures that the research output directly benefits the local agro-ecosystems. When the KAK recommends a new variety or a water management practice, farmers can be confident that the technology has been proven effective under their exact local conditions. The resulting trust accelerates the adoption rate of innovative practices, leading to measurable increases in productivity, resource efficiency, and farmer income within that specific zone. This focus on regional relevance turns the KAK into an indisputable knowledge and resource hub for the area it serves.

4.6 Farmer-Linked Research

The mission of connecting cutting-edge agricultural science to grassroots farmer needs is executed through three integrated mechanisms: On-Farm Trials (OFTs), Participatory Plant Breeding (PPB), and Weather-Linked Advisory Systems. OFTs are the crucial bridge for technology validation. Scientists test innovative technologies (e.g., a specific fertilizer dose, a new pest management method) directly on a farmer’s field under their resource constraints and management practices. This ensures that the technology is not only scientifically sound but also locally adaptable and economically viable, providing immediate, evidence-based feedback to researchers.

Participatory Plant Breeding (PPB) is the highest form of grassroots collaboration. Instead of breeding new varieties only in research stations, scientists and farmers co-select and co-evaluate promising breeding lines. Farmers contribute invaluable traditional knowledge about local preferences, stress resilience, and post-harvest quality, accelerating the selection of climate-resilient, farmer-preferred varieties and significantly boosting their adoption rate. Finally, Weather-Linked Advisory Systems translate complex agrometeorological data into simple, actionable advice. Using digital tools like apps and IVR, farmers receive timely alerts on expected rainfall, temperature extremes, or disease risk outbreaks. This information allows them to make crucial, proactive decisions on irrigation scheduling, pesticide application, and harvesting, directly mitigating weather-related losses and optimizing resource use at the field level.

4.7 Integration with National Missions

The mission-oriented KAKs will achieve large-scale, synergistic impact by ensuring complete integration with national missions, thereby aligning regional research priorities with overarching national goals.

4.7.1 Synergy with National Initiatives - The KAKs will be explicitly designed to function as the implementation and validation arm for major government initiatives.

- National Innovations in Climate Resilient Agriculture (NICRA): KAK research on climate-smart farming and developing climate-resilient crop varieties (e.g., drought-tolerant millets, heat-resistant wheat) directly feeds into the NICRA framework. KAKs function as the local testing grounds, validating the cost-effectiveness and adaptability of NICRA technologies before their wider rollout. This ensures that national investment is channeled towards solutions proven effective at the grassroots level.

- Atmanirbhar Krishi (Self-Reliant Agriculture): This mission is supported by the KAKs' focus on local self-sufficiency. The Germplasm Repositories promote the revival and improvement of indigenous, region-specific varieties, reducing reliance on external inputs. Furthermore, the Bioresource Valorization theme helps farmers build local value chains for farm waste, fostering rural entrepreneurship and creating a circular agricultural economy, which is key to achieving economic self-reliance.
- Digital Agriculture Mission: The KAK's Data & Monitoring Cell and Weather-Linked Advisory Systems are foundational to the Digital Agriculture Mission. KAKs provide the ground truth data necessary to train AI models and mobile applications, ensuring advisory services are accurate and location-specific. By using digital platforms (IVR, apps) for extension, the KAKs actively drive the adoption of data-driven farming, accelerating the digital transformation of agriculture at the district level. This deliberate harmonization prevents duplication of effort, maximizes resource utilization, and ensures that research findings are rapidly scaled up through established national and state-level extension networks.

4.8 Teaching and Mentoring

The KAKs are explicitly defined as mission-oriented research and innovation hubs, meaning their primary focus is the translation of science into scalable technology and regional problem-solving, not the delivery of formal academic degrees. To maintain this core focus and avoid diluting their limited scientific resources, KAKs will not conduct any formal educational programs, like undergraduate or postgraduate courses. However, KAKs will play a vital, complementary role in agricultural education through strategic collaboration with local universities and colleges. This partnership is essential for bridging the gap between academic theory and practical, field-level relevance. KAK scientists, with their specialized, on-the-ground expertise in climate-resilient agriculture, germplasm, and precision farming, will deliver specialized guest lectures and conduct seminars at nearby academic institutions. This exposure will ensure that the next generation of agricultural professionals is trained in the cutting-edge, regionally relevant technologies developed by the KAKs. Furthermore, the KAKs will serve as living laboratories for students. Scientists will guide M.Sc. and Ph.D. students in their research, offering access to their advanced facilities, germplasm repositories, and real-time field trials. This mentorship allows students to conduct thesis work that directly addresses the immediate, mission-driven challenges of the agro-climatic zone, providing them with invaluable practical experience and ensuring the continuity of the research pipeline. This symbiotic relationship strengthens local academic programs without diverting the KAK's resources from its core mandate of innovation and extension.

4.9 Excellence for Equitable Growth

The mission-oriented KAKs under the BKAP are designed to operate as regional Centers of Excellence, moving beyond traditional research to focus on mission-driven, integrated agricultural development. Their core function is to ensure the long-term sustainability and resilience of regional agriculture. Each KAK will serve a pivotal role in preserving genetic wealth by establishing and maintaining Germplasm Repositories for climate-resilient, indigenous, and underutilized crops specific to its agro-climatic zone. Concurrently, they are dedicated to advancing adaptive research through focused efforts on mission themes like soil health, water-use efficiency, and bioresource valorization. This research is translated into practical technologies *via* OFTs and PPB, ensuring solutions are relevant and acceptable to local farmers. Crucially, KAKs integrate agrometeorological insights by linking real-time weather data with farmer-centric innovation, developing accurate Weather-Linked Advisory Systems to mitigate crop losses and optimize resource use. This integrated approach effectively connects cutting-edge science to the immediate, grassroots needs of the farming community.

Advantages of Mission-Oriented KAKs: The unique structure and mandate of the mission-oriented KAKs offer significant advantages over traditional research models.

- Hyper-Local Relevance and Adoption: By aligning with the NARP Agro-climatic Zones, KAKs ensure that every research output from a new seed variety to a farming practice is proven and validated under the precise local soil, pest, and climate conditions. This regional focus is the single greatest factor in accelerating the adoption rate of modern technologies, ensuring research funding directly translates into farmer benefits.
- Climate Change Resilience: The core missions of germplasm conservation and climate-smart farming make KAKs the bulwark against climate threats. They rapidly breed and disseminate stress-tolerant varieties and provide real-time, weather-based advisories, which are essential for minimizing crop losses and ensuring stable farmer incomes in volatile weather years.
- Efficiency and Resource Mobilization: Operating under clear mission themes prevents the diffusion of effort. The integration of the Data and Monitoring Cell ensures activities are evidence-based and accountable. Furthermore, the Partnership and Outreach unit efficiently links with State Agricultural Departments (SADs), ICAR, and Agri-Startups, creating a powerful synergy that multiplies the available resources and ensures seamless scaling of successful technologies through established state extension channels.
- Strengthening the Digital Ecosystem: KAKs serve as the ground-truthing layer for national initiatives like the Digital Agriculture Mission. By collecting standardized farm data and refining digital decision-support systems, they provide the essential, high-quality information required for developing effective, personalized advisory services. This integration makes the national digital ecosystem more intelligent and reliable, leading to precision farming that is accessible to small and marginal farmers.

4.10 Allocation & Equity Formula (Proposal)

To operate equality, allocate baseline funding, and provide needs-based top-up. Example weighting (illustrative):

• 30%: baseline operational minimum (ensures simplicity and parity),

• 30%: agricultural population served (scale of outreach),

• 20%: vulnerability score (drought/flood frequency, climatic risk),

• 20%: socio-economic disadvantage (smallholder density/poverty).

This ensures each zone can stand up an effective KAK while disadvantaged zones receive extra resources as per equity approaches recommended in the USDA.

4.11 Implementation Phasing and Quick Wins

• Phase 1: (0–12 months): National KAK + 5 pilot zonal KAKs (choose a mix: Himalayan, Western Dry, Lower Gangetic, Central Plateau, Island). Standardize SOPs, test dashboard, run 2 cropping season trials.

• Phase 2: (12–36 months): Rollout remaining zonal KAKs, formalize sub-regional/state hub partnerships, scale mobile KAKs.

• Quick Wins: Climate-ready cropping calendars for the top 3 crops per zone, seed throughput improvement (quality seed hubs), district-level training of extension staff using demo plots.

5.0 The Key Logistics for Implementation

The success of the mission-oriented KAKs under the BKAP hinges not just on their innovative mandate but on meticulous planning and the development of a clearly defined modus operandi. These centers are intended to drive national and regional prosperity, a goal that requires a balanced growth trajectory across India's diverse agricultural landscape. This planning imperative necessitates immediate action on several key logistical and strategic fronts, ensuring every KAK is launched with maximum efficiency, impact, and operational clarity.

5.0.1 Strategic Alignment and Infrastructure Validation - The initial step in establishing the KAKs is a critical exercise in resource optimization, validating potential hosts by consulting existing inventories of the ICAR and SAUs. The rationale here is simple by leveraging established infrastructure significantly accelerates the transition from planning to action. By co-locating KAKs within or adjacent to existing institutes, the program immediately gains access to essential assets such as functioning laboratories, experimental farmland, administrative blocks, and staff housing. More crucially, this strategy allows the KAK to tap into existing human capital and institutional knowledge, enabling the core research and data units to become operational almost immediately, bypassing years of construction and procurement delays. This minimizes capital expenditure, redirects funds toward mission-critical research, and ensures the KAKs begin contributing to regional prosperity from day one. A KAK's operational design must be built upon this foundation of existing public sector constructive collaboration.

5.0.2 Suggested Model - The proposed KAKs are not additional centers to the present ICAR units but to replace all the RIs, NRCs, AICRPs, etc. It means in a region, one existing ICAR institute will be a zonal KAK, and the resources of all other existing RIs or NRCs, etc., will be consolidated in it. Some of the units still serve as Sub-Centers (Krishi Anusandhan Upa-Kendras). The remaining RIs, NRC, etc., may be handed over to the respective close SAUs. One such example may be shown using Kolkata as a zonal KAK where institutes like the following will be merged.

1. National Institute of Natural Fiber Engineering & Technology (NINFET), Kolkata
2. Central Research Institute for Jute & Allied Fibers (CRIJAF), Barrackpore, Kolkata
3. Central Inland Fisheries Research Institute (CIFRI), Barrackpore, Kolkata
4. Agricultural Technology Application Research Institute (ATARI), Kolkata
5. ICAR -Central Institute of Fresh Water Aquaculture, Bhubaneswar
6. ICAR - CRRI Cuttack
7. ICAR - Indian Institute of Management, Bhubaneswar
8. ICAR - Central Institute for Women in Agriculture, Bhubaneswar.

Regional Research Stations of ICAR

1. Eastern Regional Station of ICAR-NDRI, Kalyani, Nadia
2. ICAR-CTRI Research Station, Dinhata, Cooch Behar
3. IARI Regional Station, Kalimpong, Darjeeling
4. ICAR-Regional Research Centre of CIBA, Kakdwip, 24 Parganas (South)
5. ICAR-CIFE Centre, Salt Lake City, Kolkata
6. Regional Research Centre of ICAR-CIFA, Rahara Fish Farm, Rahara
7. ICAR-CPCRI, Research Centre, Mohitnagar, Jalpaiguri
8. ICAR-CSSRI Regional Research Station, Canning Town, 24 Parganas (South)

9. ICAR-CISH Regional Research Station, Makhdumpur, Malda
10. Eastern Regional Station of ICAR-NDRI, Kalyani.

5.0.3 Regional Coordination in Agricultural Research, the Imperative for ICAR-SAU Synergy - The Indian Council of Agricultural Research (ICAR) system, alongside State Agricultural Universities (SAUs), forms the backbone of the nation's agricultural science and education. However, the concentration of multiple specialized ICAR institutions and their Regional Research Stations (RRSs) within a single, homogenous agro-climatic region often leads to organizational fragmentation, duplication of research effort, and sub-optimal resource utilization. To move from mere co-existence to genuine collaboration, establishing a formal regional-level coordination mechanism is not merely beneficial. It is an operational necessity for maximizing the return on public investment in agricultural R&D. The primary objective of such a coordinated framework must be the clear delineation of research responsibilities. Duplication of work where multiple agencies pursue similar objectives for the same crop or issue is a profound waste of scarce budgetary and human resources. A regional coordination council, involving the heads of all mandated ICAR institutes and the Vice-Chancellors of network SAUs, must collaboratively review existing research mandates and define lead and supporting roles. ICAR institutes, with their specialized national mandates (e.g., specific crops, soil, or water management), should focus on cutting-edge, strategic research, while SAUs, with their stronger regional connection, can concentrate on adaptive, location-specific trials and validation. This fixed responsibility ensures every scientist and facility contributes uniquely to the regional research agenda.

Furthermore, constructive collaboration is essential for the effective utilization of resources, especially high-value assets. Modern agricultural research requires expensive infrastructure, such as genomics labs, high-throughput phenotyping platforms, and advanced analytical equipment, which should be treated as shared regional assets rather than exclusive institutional property. The coordination mechanism must develop protocols for joint use and maintenance. The partnership with SAUs is particularly critical here, leveraging their widespread network of KVKs and field stations. This network provides the ICAR institutions with an immediate, deep-rooted extension arm and a massive testing ground, transforming theoretical research outcomes into validated, scalable field practices.

Finally, effective coordination is defined by its ability to translate research findings into tangible benefits for farmers. The current fragmented system often results in conflicting or confusing messages delivered by various research and development agencies. The proposed regional coordination body must develop a consolidated statement for the transfer of technology, synthesizing validated recommendations from all networked institutions into a unified, actionable package of practices. This statement must then form the basis of a continuous, proactive dialogue with the State Development Departments (e.g., Agriculture, Horticulture, Irrigation). By integrating the research agenda with the state’s development priorities and extension machinery, the consolidated statement ensures that technology transfer is not a sporadic activity, but a streamlined, consensus-driven process that directly influences state policy and reaches the last mile with clarity and authority. This institutionalized collaboration is the vital step toward accelerated, impactful regional agricultural development.

5.0.4 Tiered Planning and Hub-and-Spoke Model for Regional Agricultural Extension - Effective regional coordination requires a strategic planning process to define the optimal deployment structure for research and extension assets across vast agro-climatic zones. The initial critical decision lies in determining if each sub-zone, often corresponding to a National Agricultural Research Project (NARP) area, requires a dedicated, fixed satellite service point for localized extension and data collection, or if they can be more efficiently served by grouping them under larger, mobile, state-level hubs. This decision matrix must consider geographical size, existing road infrastructure, population density, and, critically, the degree of agro-ecological heterogeneity within the sub-zones. The goal is to maximize last-mile connectivity without duplicating permanent, high-cost infrastructure. The suggested refinement establishes the KAK or the designated lead ICAR institution for the zone as the central Centre of Excellence (CoE). This hub is strategically positioned to handle high-level, capital-intensive functions that cannot be decentralized. Its core responsibilities must be focused on mission-driven strategic research, acting as the custodian for regional germplasm storage, and housing high-end diagnostics and molecular biology labs. By centralizing these core assets, the KAK maintains a laser focus on generating breakthrough science and providing the advanced analysis required to tackle complex, systemic agricultural challenges. This is where scientific depth is concentrated and maintained. The central KAK, however, cannot succeed without the crucial 'spokes' reaching the field. This is achieved through the utilization of a fleet of mobile units. These units are designed to be agile, fully equipped with basic soil and water testing kits, and staffed by multi-disciplinary teams, including technicians and specialized extension workers. Their operational command lies with the CoE, but their daily routes are mapped to penetrate the more numerous, smaller NARP subzones. This design ensures that the specialized scientific outputs from the central KAK are delivered directly to farmers, validating technology under diverse, real-world conditions.

Crucially, the mobile units serve a dual function, forming the basis of a vital localized data feedback system. While delivering technology, they actively collect field data on pest incidence, soil health parameters, adoption rates, and farmer feedback from the subzones. This granular, real-time intelligence is fed back to the central KAK. This process closes the loop: research informs extension, and extension data immediately refines the research agenda, ensuring that the CoE remains highly responsive to genuine farmer needs. This tiring, hub-and-spoke model guarantees efficiency. Specialized research remains focused and well-resourced at the KAK, preventing resource dilution. Simultaneously, mobile units ensure that extension delivery achieves the necessary deep penetration and adaptive capacity across the entire operational command. This architecture is the most cost-effective way to utilize pooled resources and develop a consolidated, authoritative transfer of technology statement in dialogue with State Development Departments, driving balanced and impactful growth across the region.

5.0.5 Co-Design and Defining the Modus Operandi - The most critical planning element for the KAKs is the development of a clear, non-overlapping modus operandi through intensive stakeholder consultations. Before any KAK is fully funded, detailed consultations must be held with State Agriculture Departments (SADs), existing Krishi Vigyan Kendras (KVKs), and representatives of regional farmer groups. These sessions are not merely for informational purposes; they are for co-designing extension delivery modalities. The KAK must establish a clear functional demarcation:

- The KAK's role is specialized research, technology translation (e.g., new germplasm, precision farming DSS), and high-level training (Training-of-Trainers).
- The KVK's role remains the primary, on-the-ground extension and capacity building arm.
- The SAD's role is mass scaling and integrating KAK technologies into state subsidy and scheme frameworks.

A key output of these consultations must be formal agreements or Memoranda of Understanding (MoUs) that define the data sharing protocols, joint programming responsibilities, and financial commitments from all parties. This clarity eliminates organizational friction, ensures that the KAK's research is immediately relevant to the state's extension needs, and, most importantly, provides farmers with a unified, coherent message. This strategic clarity, stemming from a well-defined MoUs, is the only way to guarantee that the KAK network drives a unified national agricultural agenda, ultimately contributing to both regional specialization and overall national prosperity through equitable and balanced growth across all corners of the Country.

6.0 Recommendations

The proliferation of ICAR institutions and SAUs within the same agro-climatic region necessitates a transformative shift from loose coordination to a structured, mission-critical framework for agricultural development. The proposed tiered, hub-and-spoke model serves as this framework, centralizing scientific depth while ensuring comprehensive last-mile delivery. The ultimate success of this network rests on three actionable recommendations:

- **Institutionalize Functional Demarcation:** Formally assign specialized roles to prevent resource duplication. The KAK must be cemented as the Centre of Excellence for strategic research and technology translation, leaving the KVKs as the dedicated, on-the-ground extension and capacity builders, and the SADs as the sole agencies for mass scaling and subsidy integration.
- **Establish a Robust Feedback Loop:** The KAK's mobile units must not only deliver technology but also systematically collect field data from NARP subzones. This granular, real-time intelligence must be continuously integrated back into the KAK's research agenda to ensure scientific outputs remain demand-driven and highly relevant to farmer needs.
- **Mandate Formal Agreements (MoUs):** The coordination among KAK, KVK, and SAD must be codified through legally binding Memoranda of Understanding. These agreements are essential for clarifying joint programming, detailing data-sharing protocols, and securing financial commitments. The MoUs eliminate organizational friction and are the only reliable mechanism to guarantee that the farmer receives a single, unified, and authoritative package of practices endorsed by both the research and development arms of the state.

By adopting this strategic clarity and formalizing collaboration, the KAK network can transition from a collection of fragmented institutions to a unified engine for regional agricultural specialization and equitable national growth.

7. Concluding Remarks

Any research organization, irrespective of its legacy or initial achievements, is fundamentally a public trust, and if it carries out its core mandate as a mere routine day-to-day affair, it is destined to ossify, becoming tragically irrelevant and ultimately unable to meet the expectations of the very people it was established to serve. Stagnation is not merely a risk, but a compulsive decay; the administrative inertia that settles over a successful institution soon blinds it to the dynamism of the external world. Therefore, it is a **compulsion**, not an option, to constantly and continuously evolve the entire management and delivery system. This evolution must be a strategic, integrated process, proactively matching the institution's output with three critical external drivers: first, the accelerated **advancement of technology**, which demands agile adoption of new tools and methods for research and delivery; second, the rapidly shifting **societal needs**, which require continuous re-evaluation of research priorities, moving beyond traditional concerns to address emergent challenges like climate resilience, malnutrition, and complex market demands; and third, the precise **aspirations of the clientele**, which necessitate developing robust, high-speed outreach mechanisms. Efficiency and impact can no longer be seen as separate goals; they must be fused through efficient management systems that dismantle bureaucratic silos, shorten the innovation-to-field cycle, and measure success not by publications, but by tangible benefits delivered to stakeholders. The failure to undertake this relentless self-renewal transforms the organization from an engine of national progress into a liability—a drain on resources whose mandate is obsolete. Only through this commitment to constant, rigorous self-upgradation can a public research body justify its existence and truly become a responsive, cutting-edge instrument dedicated to collective prosperity.

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Bioenhancer: A potential tool to improve yield and quality of crops in organic crop production

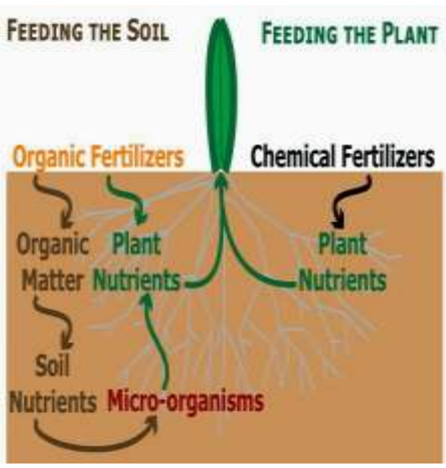
Introduction

Bioenhancers are organic preparations, obtained by active fermentation of animal and plant residues over specific duration. These are the concentrated manures, bio products in powder or liquid form, henceforth termed as bioenhancer. These are rich source of microbial consortia, macro, micronutrients and plant growth promoting substances including immunity enhancers. Utilized to treat seeds/seedlings, enhance decomposition of organic materials thereby enrich soil and induce better plant vigor. Based on local experiences and given specific names viz., Amritpani, Panchagavya, Bijamrita, Jeevamrita etc. Similarly in biodynamic farming, few effective preparations such as BD-500, BD-501, Cow Pat Pit, biodynamic liquid manures/bio pesticides and in homa organic farming.

Characteristics of bioenhancer

1. Potent source for macro and micro nutrients
2. Presence of plant growth promoting factors
3. Immunity enhancer
4. Pesticidal and fungicidal property
5. Efficacy of its influenced by inputs used and method of preparation
6. Used for seed/seedling treatment, enhancing decomposition of residues, improving soil fertility and productivity .

Bioenhancer to improve nutrient status and soil properties



Classification of bioenhancers

1. Plant based: These are prepared from tender plant parts and leaves viz., sunhemp, dhaincha (Sesbania), erythrina and other legumes which are potent source of nitrogen, leaves of neem, pongamia, subabul, gliricidia, lantana, calotropis and other local plants having pesticidal properties, weeds viz., Parthenium, stinging nettle, Cassia tora etc.

2. Animal based: These are prepared with cattle dung, sheep and goat dropping, fish manures *etc.* Combination of plant and animal byproducts have better impacts on crop production. Organic liquid manures play a key role in promoting growth and providing immunity to plant system (sreenivasa *et al.*, 2010)

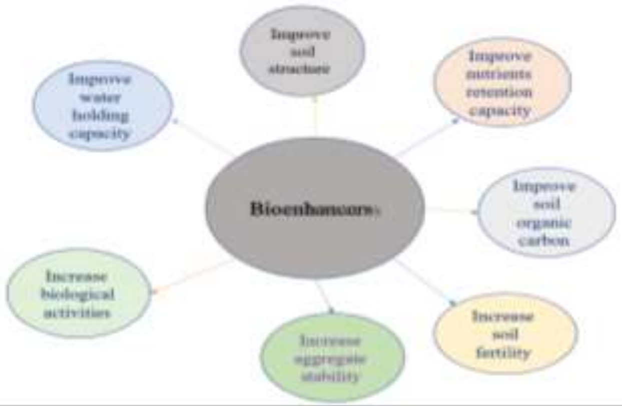
Type of bioenhancers based on preparation

- **Simple bio enhancers:**
  - ✓ Cow urine
  - ✓ Biogas slurry
  - ✓ Matka khad
  - ✓ Charota (*cassia tora*)

Biodynamic liquid manure: BD 500, BD 501

Cow pat pit (CPP), Amrit-mitti, Panchagavya, Dasagavya, Jivamrut, Kunapajal, Vermiwash, Agnihotra ash

Bioenhancers and its effect on soil



Effect of bioenhancer on plant health

- ✓ Stress and premature deterioration reduction
- ✓ Germination improvement
- ✓ Translocation of nutrients improvement
- ✓ Toxics neutralization
- ✓ Soil microbial activity stimulation
- ✓ Storage and absorption of nutrients improvement
- ✓ Cation exchange capacity improvement
- ✓ Root growth stimulation
- ✓ Stress and deterioration reduction

Strategy for promotion of bioenhancers

- ✓ Indian farmers are not aware to that dairy and field by products (urine, dung, crop wastes *etc.)* have good nutritional values which are used for preparation of organic fertilizers, so needs to aware farmers about this
- ✓ These can be prepared with little support and skill up gradation trainings
- ✓ There is need for delineation of nutrient status (macro and micro nutrients), microbial consortia, plant growth promoting factors, immunity enhancer ability *etc*. for their quick acceptance by the scientific and farming community
- ✓ After proper filtration, bioenhancers can be used through drip/sprinkler as fertigation
- ✓ Comparative evaluation of aforesaid bioenhancers for their nutritive value and impact will help for their preparation and use
- ✓ There is need to work out its contribution in organic production and frequency of their use in different crops

Effect of bioenhancer on growth and yield, including its quality and economics

The application of Panchagavya(3%) with FYM has shown significant impacts on the growth and yield of green gram. Many Studies indicate that combining Panchagavya(3%) with FYM can lead to enhanced growth metrics and increased yield of crops (Chongre *et al*., 2019). Foliar spray of Jeevamrut at 15 and 30 DAS increased SPAD chlorophyll readings and overall leaf greenness in mungbean (Swami *et al*., 2021). In chickpea trials, liquid organic manures such as Panchagavya (3%) significantly improved growth and yield attributes compared to control treatments (Yadav *et al*., 2017).

The applications of Panchagavya @ 3% with FYM 6 t/ha at 30, 45 and 60 DAS raised wheat grain weight per plant and total grain yield (Javiya *et al*., 2019). Cowpea growth, LAI, yield and benefit–cost ratio improved under 3% Panchagavya spray (25 & 45 DAS) treatment, showing economic as well as agronomic benefits (Meyyappan and Sivakumar, 2020). Pea plants treated with bioenhancers exhibited greater plant height and higher pod yield, demonstrating positive vegetative and yield responses (Bharadwaj *et al.*, 2021).

Summer greengram receiving integrated bioenhancer treatments such as seaweed extract @ 10% showed increased nutrient content, protein percentage and protein yield at harvest (Chaudhary *et al.*, 2021). Wheat growth and yield attributes such as plant height and spike length were enhanced by Jeevamrut @ 20% (2 weeks interval), contributing to increased grain yield in hill agro-ecologies (Kaur, 2021). Yield, harvest index and profitability of wheat improved under Poultry Manure 3.0 t/ha with Panchagavya 3% with Vermiwash 3% applications, demonstrating both productivity and economic benefits (Praneeth *et al.*, 2021).

Integrated nutrient management including bioenhancers produced higher yield and nutrient uptake in foxtail millet than inorganic-only treatments (Veerendra *et al.*, 2021). Late-sown wheat receiving treatments of 100% RDN + panchgavya as foliar spray @ 3% at 30, 45 and 60 DAS showed improved growth, higher grain yield and better economics than late-sown control plots (Choudhary *et al.*, 2022). In rapeseed trials, application of 1tonne vermicompost/ha as basal + vedic panchagavya foliar application (3%) increased plant height, branches per plant and seed/oil yield, improving farmer returns (Nilakhi *et al*., 2023). Studies at Kanpur reported that combined use of bioenhancers with manures improved plant height, rice tillering and final grain yield (Varma *et al.*, 2024).

Conclusion

- ✓ Bioenhancers could be a potent source to improve soil fertility and crop productivity.
- ✓ Bioenhancers, have potential to reduce use of chemical fertilizers and provide high quality products. However, care should be taken that bioenhancers can not meet the entire nutrient requirement of the crops in limited quantity.
- ✓ Apply bioenhancer like panchagavya(3%), jivamrut application, seaweed extract (10%) and varmiwash(3%) along with vermicompost and FYM in optimum amount to meet the

nutritional requirement of crops.

- ✓ Its simply catalyze the quick decomposition of crop residues and animal waste, which is prerequisite for improving soil fertility and crop productivity.
- ✓ Bioenhancers combined with manures and frequent use can address many challenges of agriculture and will be pave way for sustainable agriculture through organic resources.

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INSECT PESTS OF MEDICINAL CROPS AND THEIR MANAGEMENT

Introduction:

Medicinal crops are those crops which involves use of plant parts, which secrete substances that are being used for therapeutic purposes and often forms as precursor for synthesis of useful herbal drugs. In today's time, most of the people are preferring herbal drugs over modern drugs due to their side effects. Many medicinal crops contain bioactive compounds (Alkaloids, Glycosides, Steroids, Phenols) that are used as anti-cancer, anti-helminthic and widely used as medicine.

Sl.No	Common Name	Scientific Name	Order
1.	Cutworm	*Agrotis sp.*	Lepidoptera
2.	Aphid	*Myzus persicae*	Hemiptera
3.	Epilachna beetle	*Henosepilachna vigintioctopunctata*	Coleoptera
4.	Whitefly	*Bemisia tabaci*	Hemiptera
5.	Fruit borer	*Helicoverpa armigera*	Lepidoptera
6.	Mealy bug	*Dysmicoccus brevipes*	Hemiptera
7.	Tea mosquito bug	*Helopeltis theivora*	Hemiptera
8.	Seed beetle	Lasioderma serricorne	Coleoptera
9.	Mealy bug(Ashwagandha)	Coccidohysterix insolitus	Hemiptera
10.	Ash Weevil	Myllocerus viridanus	Coleoptera

1. **Cutworm:** *Agrotis sp.* , Lepidoptera

Host range: Ashwagandha, Belladona, Opium poppy and Sarpagandha, Isabgol.

Damage Symptoms: Larvae attacks the tender seedlings during early summer months. Defoliation also occurs intensively. Partially cut plants may wilt and dry up. Irregular feeding marks on the lower stem near the collar region. Small burrows or cracks in the soil are found. More damage seen during germination and early vegetation stages.

Management:

- Handpicking of caterpillars and destroy it.
- Spray 5% NSKE.
- Plough the field after harvesting the crop to expose hibernating pupae.

- Installation of light traps and Pheromone traps to monitor and attract male moths.
- Use of Poison Bait to lure the larvae.
- Drenching the collar region of the plants in evening hours with Chlorpyriphos @ 2ml/lit. a day after planting.

2. **Aphid:** *Myzus persicae* , Hemiptera

Host range: Yam and Long Pepper.

Damage Symptoms: The nymphs and adults suck the plant sap from tender leaves and stems of young vines, causing severe damage to young seedlings. As a result, new growth is adversely affected.

Management:

- Spray NSKE 5%.
- Installation of Yellow Sticky traps.
- Encourage natural enemies like Coccinellid beetles.
- Spraying Triazophos20 ml (Hostathion 40 EC) or Acephate @ 0.15% or Imidacloprid 5 ml.

3. **Epilachna Beetle:** *Henosepilachna vigintioctopunctata* , Coleoptera

Host range: Ashwagandha and Sarpagandha.

Damage Symptoms: Grubs and adults feed by scraping chlorophyll from epidermal layers of leaves, leading to skeletonisation of leaves, leaves dry away.

Management:

- Collection of Grubs and Adults and destroy it.
- Spray Carbaryl 50 WP 2g/ lit. mixed with wettable Sulphur 50 WP @ 2g/ litre of Water.

4. **Whitefly:** *Bemisia tabaci* , Hemiptera.

Most commonly infested on Keezhanelli.

Damage Symptoms: The nymphs and adults such the cell sap from tender leaves and stems, leading to weakening and wilting of plants. Leaf Chlorosis, Withering and premature dropping of leaves leading to death of plant.

Management:

- Collection and destruction of infested plant parts.
- Spray NSKE @ 5% or Neem oil @ 3%.
- Apply Methyl Parathion or Lindane dust in the field to arrest ant activity.

5. **Fruit Borer:** *Helicoverpa armigera* , Lepidoptera.

Host range: Ashwagandha and Opium Poppy.

Damage Symptoms: Neonates after hatching feed on tender leaves, later they bore into fruits, also on flower heads and seeds of flower.

Management:

- Field release of *Trichogramma chilonis*@ 5 cards.
- Spray application of NPV @ 250 LE /ha.
- Setting up Pheromone traps @ 12 traps/ha.

6. **Mealy bug:** *Dysmicoccus brevipes* , Hemiptera

Host range: Long pepper and Sarpagandha.

Damage Symptoms: Nymphs and adults are found on the under surface of leaves, sucks the plant sap from tender leaves and stems. Affected plants turn yellow, wilt and dry. Roots are also affected severely. Stunted growth of plants. Honey dew secretion leading to development of sooty mould, thereby affecting photosynthetic efficiency.

Management:

- Removal of affected plant parts in the early stage of attack.
- Soil application of neem cake @ 150kg /ha.
- Soil drenching with Dimethoate @ 2ml / litre near the root zone of affected plants.
- Field release of Coccinellid predators.

7. **Tea Mosquito bug:** *Helopeltis theivora* , Hemiptera

Severely infests Long Pepper.

Damage Symptoms: Nymphs and adults suck the plant sap from tender leaves, stems and inflorescence. Necrotic lesions develops around the feeding punctures leaving shot holes on the lamina.

Management: Spray Monocrotophos or Phosalone @2ml / lit. of water in the evening hours for better control.

8. **Seed beetle**: *Lasioderma serricorne* , Coleoptera

Host range: Isabgol

Damage symptoms: It is a serious pest of seed in storage. Both grub and adult cause damage by feeding on the internal contents of the seed.

Management : Seed treatment with 2% neem/pongamia oil protects them from beetle damage.

- Seed treatment with 0.05% chlorpyriphos.

9. **Ash weevil**: *Myllocerus viridanus*, Coleoptera

Host range: Ashwagandha

Damage sysmptoms: The adult cause damage by feeding on leaves from edges in a characteristics manner resulting in severe defoliation and the grub feeds on the roots leading to wilting and drying of plants.

Management : Soil application of malathion dust or drenching of soil with 0.1% chlorpyriphos to kill the grubs.

Conclusion : In recent years the health hazards and toxicity caused by synthetic drugs has been increased for which the interest of using the plant based product has grown. A campaign is going on worldwide to utilise more and more plant derived chemicals in the human health care system.Nearly 70% of synthetic drugs are derived from plants and some of the population relies on traditional medicines. Unless we start cultivating the important medicinal plants, it is not possible to meet the increasing demands. Therefore healthy plant material is therefore essential for maintaining the product quality.

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Mentimeter in Action: Boosting Efficiency and Outlook of KVK Professionals

Introduction

Getting people to actively participate whether in a classroom, training hall, or corporate meeting is never easy. Traditional slides often leave audiences passive and uninspired. In many training sessions and workshops, the voices of participants remain unheard—not because they lack ideas, but because they hesitate to step forward. Fear of judgment or being identified in public often silences genuine opinions and discourages interaction. As a result, presenters frequently experience the session as one-way communication with limited participation. Collecting honest feedback is also difficult, as participants avoid giving immediate responses. Consequently, the feedback remains incomplete, leaving several important questions unresolved. Now, with creative approaches and digital tools, we can create safe spaces for sharing views, where silence is transformed into vibrant dialogue. In such an environment, participants feel confident to contribute, and the full potential of collective learning is unlocked. Mentimeter, a web-based presentation tool, changes this by transforming one-way lectures into two-way conversations. With polls, quizzes, word clouds, and live Q&A, it turns passive listeners into active contributors. Mentimeter offers a way to shift from static slide decks to interactive experiences. Instead of speaking at an audience, presenters can run live polls, quizzes, or Q&A sessions that invite real-time input from every participant. From agricultural extension by KVK professionals to classroom teaching, corporate training, and large-scale events, Mentimeter is reshaping the way engagement and participation are achieved.

What is Mentimeter?

Mentimeter is a web-based tool that makes presentations interactive through real-time audience participation. It allows presenters to integrate polls, multiple-choice questions, word clouds, scales, and open-ended prompts, enabling participants to contribute responses in real time through a browser link, code, or QR scan. Their responses appear instantly on the main screen as charts, graphs, or word clouds, making sessions more engaging and participatory. Mentimeter is easy to use and works well in classrooms, meetings, workshops, and events. It helps presenters get feedback, check understanding, and keep everyone involved.

Why educators and facilitators love it?

- Simple to set up
- Works on any device
- Encourages even shy learners to contribute
- Provides instant feedback to guide discussions

Uses of Mentimeter

Mentimeter makes classrooms, meetings, and events more engaging by turning passive listening into active participation.

- **Classrooms:** Run quizzes, polls, or word clouds to check understanding and involve students.
- **Meetings/Workshops:** Collect instant feedback, brainstorm ideas, and rank priorities.
- **Events/Conferences:** Engage large audiences with live Q&A, polls, and voting.

Who Uses Mentimeter?

User Group	Use Case	Activities
Educators	Interactive teaching	Polls, quizzes, word clouds, Q&A
KVK Professionals	Farmer training & extension	Feedback, sharing best practices
Corporate Teams	Meetings, brainstorming	Instant polls, sentiment checks
Event Hosts	Conferences & large gatherings	Live voting, Q&A, audience ratings
Facilitators	Workshops & coaching	Real-time group input

How Does It Work?

The workflow is straightforward:

Create → Share → Join → Respond → Results → Review

1. Create interactive slides in Mentimeter with polls, quizzes, or open-ended prompts.

2. Share a join code or QR code.
3. Audience joins with a QR code or link.
4. Responses appear instantly on screen.
5. Display results instantly on the main screen.
6. Data can be exported for reflection or future planning.

Key Features

The Mentimeter application offers several features that make presentations and classes more interactive and engaging. It enables teachers and presenters to create live polls, quizzes, and surveys to test knowledge and gather opinions. The platform also integrates with tools such as PowerPoint, Google Slides, Zoom, and Microsoft Teams, making it easy to use in both classrooms and meetings.

- Live Polls – Teachers or presenters can ask questions and see audience votes instantly.

- Quizzes – Fun, game-like quizzes to test knowledge and learning.
- Word Clouds – Shows audience ideas in a colorful cloud where the most common answers appear bigger.
- Q&A Sessions – Students can post questions (even anonymously) and vote for the most important ones.
- Ranking & Rating – Lets participants rank items in order or rate them on a scale.
- Open-ended Questions – Collects detailed thoughts and feedback from students.
- Surveys – Helps gather opinions or data from the whole class or audience.
- Templates & Themes – Ready-made designs to create attractive and easy presentations.
- Integrations – Works with PowerPoint, Google Slides, Zoom, and Microsoft Teams
- Analytics & Exports – download results in Excel/PDF.

Benefits

A. **For Students & Participants**:

- Makes learning fun and interactive.
- Gives everyone a voice, even shy learners.
- Provides instant feedback on understanding.
- Increases engagement and memory retention.

B. **For Teachers & Facilitators**:

- Quick insight into student learning levels.
- Encourages reflection and lesson improvement.
- Breaks monotony of traditional lectures.
- Works well in hybrid and online sessions

Mentimeter in Action

In Education & Training

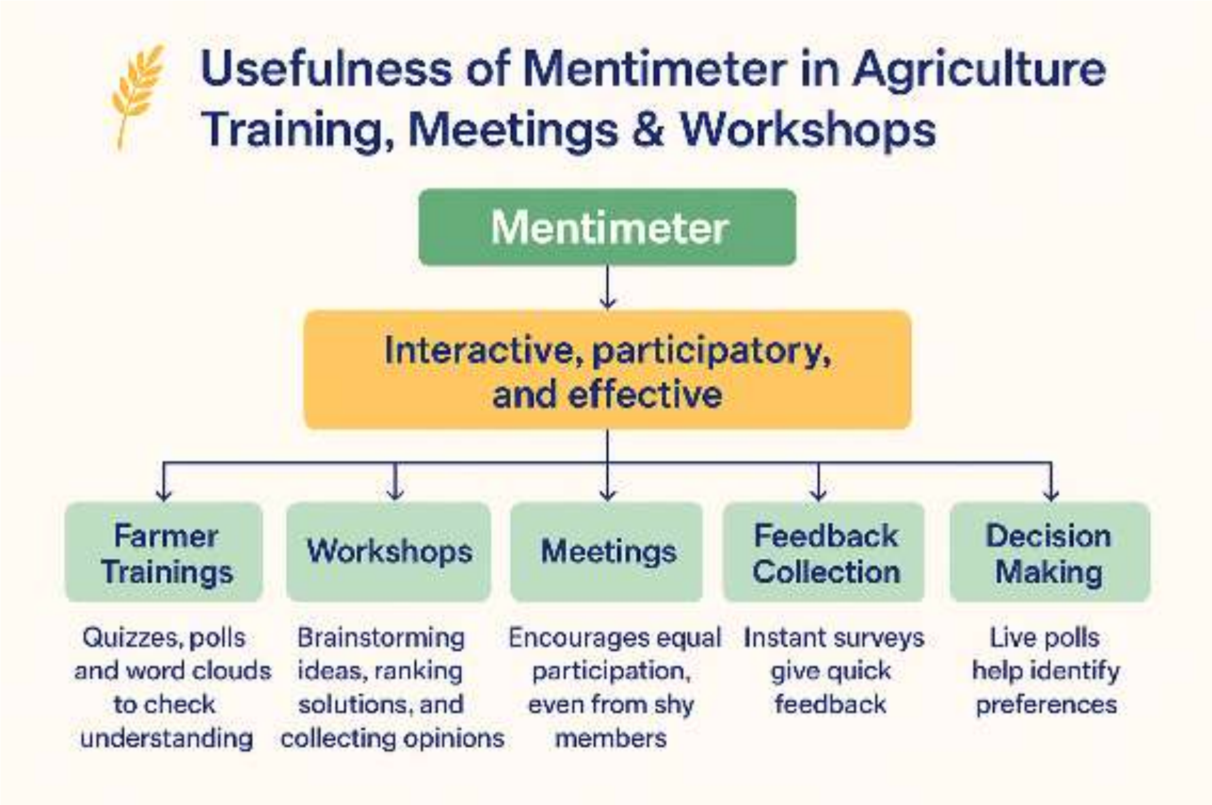
- Run quizzes to check understanding.
- Use word clouds for brainstorming.
- Allow shy students to respond anonymously.
- Export responses for lesson planning.
-

In Business & Events

- Collect feedback in hybrid meetings
- Run live polls in workshops and panels
- Engage large conference audiences with Q&A
- Run icebreaker polls.
- Collect anonymous feedback.
- Guide discussions with live input

In Agricultural Extension (KVKs)

- Gather instant feedback from farmers and extension functionaries.
- Run icebreaker polls.
- Collect anonymous feedback.
- Guide discussions with live input.
- Assess understanding of improved farming practices.



- Share climate-smart techniques in an interactive way.
- Collect insights on government schemes and policies.
- Prioritize farmers' problems through participatory inputs.
- Obtain feedback on training methods, content, and requirements.
- Capture information on technology validation and field demonstrations.
- Assess availability and use of inputs, implements, infrastructure, value addition, and processing opportunities.

Mentimeter: Pros and Cons

Pros

- **Simple to use** – No installs or accounts needed; quick setup.
- **Engaging formats** – Word clouds, polls, quizzes boost interaction.
- **Device flexibility** – Works on any phone, tablet, or computer via browser.
- **Real-time insights** – Live responses help presenters adapt on the spot.
- **Custom branding** – Higher-tier plans allow company/school identity.
- **Remote-friendly** – Great for hybrid meetings, online classes, and teams.

Cons

- **Free plan limits** – Only 2 interactive slides; no export option.
- **Basic design control** – Minimal customization compared to Power Point.
- **Requires stable internet** – Works only with reliable connectivity.

- **Anonymity drawback** – May reduce accountability in responses.

Strengths	Weaknesses
Easy to use, no downloads needed	Requires stable internet
Works on any device	Free plan limited to 2 interactive slides
Boosts participation and motivation	Limited design options compared to PowerPoint
Supports diverse learning styles	Anonymity may reduce accountability

Alternatives to Mentimeter

While Mentimeter is widely used, it also has certain limitations. For example, the anonymity feature, though encouraging participation, may sometimes reduce accountability. Similarly, its design options are fewer compared to tools like PowerPoint. Several alternatives are available that can complement or substitute Mentimeter depending on the context:

- **Kahoot** – A gamified quiz platform, highly engaging for schools and younger learners, with a strong focus on fun and competition.
- **Slido** – Best suited for webinars and professional events, offering robust Q&A features and audience interaction.
- **AhaSlides** – Provides greater design flexibility and customization options, making presentations more visually appealing.
- **Poll Everywhere** – Well-integrated with Learning Management Systems (LMS) and widely used in academic settings for seamless interaction and assessment.

Case Study: "Beyond PowerPoint: Experiencing Mentimeter for Participatory Learning/Training in KVKs"

1. Background

Krishi Vigyan Kendra's (KVKs) are the grassroots institutions of ICAR, tasked with technology assessment, refinement, and transfer to farmers. While KVK scientists are well-versed in agricultural innovations, opportunities for exposure to **digital facilitation tools** in capacity-building programs are still emerging.

As part of the **Annual Zonal Workshop of ATARI Hyderabad (September 2025)**, a special exercise was conducted using **Mentimeter**—an interactive digital platform for real-time polling and visualization. The objective was not only to gather participants' reflections but also to create **awareness** and provide a **hands-on experience** with this modern engagement tool.

2. Objectives

- To introduce Mentimeter as an innovative facilitation tool to KVK scientists.
- To provide hands-on practice in responding to interactive questions using mobile devices.
- To demonstrate how such tools can enhance **trainings, farmer meetings, workshops, and reviews**.
- To spark curiosity about adopting digital engagement methods in KVK activities.

3. Methodology

- **Platform**: Mentimeter was used to host multiple formats of questions (word clouds, open text, multiple choice).
- **Participants**: Scientists and staff from KVKs across the zone.
- **Process**: During plenary sessions, participants joined Mentimeter via their smartphones and responded live to prompts. Their collective answers were displayed instantly on the screen.
- **Design**: Questions were framed in a light and engaging manner to make participation enjoyable while showing the tool's versatility.

4. Experience and Observations

4.1 First Impressions

The exercise began with the simple question: *"In one word, how do you feel about being part of KVK?"* The live word cloud—featuring responses such as **"Energetic," "Wonderful," and "Fabulous"**—immediately drew excitement and curiosity. Participants realized how quickly collective voices could be visualized.

4.2 Engagement through Creativity

Questions like *"If your KVK journey were a dish, what food would it be?"* evoked creative responses ranging from **"dal"** to **"biryani."** This demonstrated how Mentimeter can be used to trigger **imaginative thinking** and lighten formal discussions.

4.3 Interactive Fun

Polls such as *"How many cups of chai/coffee do you need to survive a KVK day?"* brought humor and relatability. Scientists laughed as results revealed a mix of "just one cup" and "three or more." The exercise showed how light questions can increase energy in long sessions.

4.4 Reflection and Honest Feedback

Open-text questions like *"What should KVK staff start or stop doing?"* encouraged candid input. Since responses were anonymous, participants freely suggested improvements like better communication, quicker documentation, and more teamwork.

4.5 Aspirations for the Future

The closing activity—*"Write a message to your future self as a KVK scientist"*—produced inspiring notes such as *"Never forget the farmer is the center of all our work."* It highlighted how Mentimeter could also be used for **vision-building exercises**.

5. Key Learnings

- **Awareness created**: Most participants were using Mentimeter for the first time, and the session helped them experience its features hands-on.
- **Versatility showcased**: From fun ice-breakers to serious reflective prompts, the tool's potential in KVK trainings was evident.
- **Positive reception**: Scientists appreciated the novelty, ease of use, and instant visualization of collective responses.
- **Potential applications**: KVKs can adopt Mentimeter in farmer trainings, review

meetings, staff capacity building, and participatory exercises.

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Conclusion

Mentimeter is more than just a digital tool—it's a helpful partner in teaching and facilitation. Instead of using static slides, it encourages real-time participation and meaningful conversations. For KVK professionals, it makes farmer training lively and collaborative. For teachers, it gives every student a voice. And for companies and event organizers, it turns routine sessions into engaging, interactive experiences

Mentimeter is a simple and effective tool that boosts engagement. It may not replace PowerPoint or an LMS, but it adds energy and interaction to any presentation—whether in a classroom, training hall, or boardroom. For anyone who values participation over passive listening, Mentimeter is a tool worth using. So, Mentimeter is best for creating simple, interactive sessions in classes, workshops, and meetings where audience input matters.

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"AFLATOXICOSIS IN DAIRY FARM ANIMALS: CAUSES, EFFECTS, AND PREVENTION"

Introduction to Mycotoxins

Mycotoxins are secondary metabolites produced by fungi that cause toxic effects in other organisms. They are cytotoxic, disrupting cell structures such as membranes and interfering with essential cellular processes, including protein, DNA, and RNA synthesis. Mycotoxins can persist even when the fungus itself is no longer visible, and they can cross species barriers, affecting both plants and animals. Many mycotoxins are heat stable and resist common food processing methods such as canning.

Fungi and Mycotoxin Production

Fungi range from single-celled organisms to complex fruiting bodies such as molds, mushrooms, smuts, and yeasts. They lack chlorophyll and absorb nutrients from living or dead organisms. Multicellular fungi develop branched tubular filaments called hyphae and reproduce via spores. These spores can spread through air, insects, birds, or contaminated equipment, infecting crops at any stage from field growth to harvesting and storage.

History and Importance of Mycotoxins

Mycotoxin contamination has been a concern for thousands of years. Ancient festivals were dedicated to protecting grain from mold, and ergotism outbreaks during the Middle Ages were early examples of fungal toxin issues. Only in recent decades have scientists isolated specific mycotoxins. Today, around 300–400 mycotoxins have been identified, with aflatoxins being among the most significant due to their severe toxic effects.

Aflatoxins: Overview and Etiology

Aflatoxins are toxic metabolites primarily produced by *Aspergillus flavus* and *Aspergillus parasiticus*. These fungi grow on crops such as peanuts, soybeans, maize, and other cereals under warm (above 70°F) and moist conditions, either in the field or during storage. The main aflatoxins include AFB1, AFB2, AFG1, AFG2, and their metabolites M1 and M2. Aflatoxicosis, caused by ingestion of aflatoxins, is a serious health problem in animals, with effects depending on species, age, nutritional status, and toxin dose.

Types of Aflatoxins and Their Metabolites

- AFB1 and AFB2: Produced by *A. flavus* and *A. parasiticus*, with AFB1 being the most toxic.
- AFG1 and AFG2: Produced by *A. parasiticus*.
- AFM1 and AFM2: Metabolites found in milk from animals consuming contaminated feed; AFM1 is a significant public health concern.
- Aflatoxicol: Another aflatoxin metabolite linked to toxicity.

Epidemiology

Aflatoxicosis occurs worldwide and has been reported in various spoiled feeds such as peanuts, corn, cottonseed meal, sorghum grain, moldy bread, and silage. The toxin is not destroyed by grain milling or ensiling. All animal species are susceptible, with outbreaks most commonly reported in pigs, sheep, cattle, poultry, and dogs. Humans are primarily exposed through contaminated food and milk, making aflatoxins a major public health issue.

Effects on Human Health

In humans, aflatoxicosis is reported in regions where environmental conditions favor fungal contamination. Studies in Asia and Africa link aflatoxin exposure to an increased risk of liver cancer. In India, food and feed contamination is common, posing risks of outbreaks.

Pathogenesis

Aflatoxins bind to nucleic acids and proteins, causing mutagenesis, carcinogenesis, teratogenesis, and immunosuppression. The liver is the primary organ affected. High doses cause severe hepatocellular necrosis, while prolonged low-level exposure may lead to liver enlargement and stunted growth. Metabolism of aflatoxins in the liver produces harmful compounds such as aflatoxin 8,9-epoxide, which intercalates into DNA and may lead to liver cancer.

Clinical Signs in Dairy Animals

Acute Clinical Signs

- Inappetence (loss of appetite)
- Vomiting (in some species, especially non-ruminants)
- Depression and weakness
- Hemorrhage or bleeding tendencies due to impaired clotting
- Icterus (jaundice) — yellow discoloration of tissues
- Rapid progression to death in severe, high-dose exposures

Subacute / Chronic Clinical Signs

- Poor growth and unthriftiness
- Weakness and lethargy
- Anorexia (reduced feed intake)
- Reduced feed efficiency
- Occasional sudden deaths
- Liver damage indicators such as elevated liver enzymes and prolonged clotting time
- In ruminants (like cattle), at higher toxin levels: reduced ruminal

Clinical Pathology and Necropsy

- Elevated serum hepatic enzymes during the acute phase.
- Detection of aflatoxins in feed, urine, blood, and tissues using chromatography or ELISA.
- Necropsy reveals liver changes such as megalocytosis, necrosis, fibrosis, bile duct hyperplasia, jaundice, and occasionally enterocolitis.

Diagnosis

Diagnosis is based on clinical history, necropsy, histopathology, and confirmation of aflatoxin presence in feed or biological samples. AFM1 detection in urine, milk, or kidney confirms exposure.

Treatment

There is no specific antidote. Treatment is mainly supportive:

- Activated charcoal may reduce absorption.
- Antioxidants like ellagic acid and cytochrome P450 inducers may provide partial protection.
- Liver function support with vitamins A, D, E, K, B complex, and high-protein diets.
- Manage secondary infections promptly. Severe cases may require blood transfusions or dialysis.

Prevention and Control

- Feed rations must be free of aflatoxins (recommended level: 0 ppb).
- Maximum safe levels:
  - Dairy cows: 20 ppb in feed; milk from cows fed above 20 ppb should not be given to calves.
  - Beef cattle: ≤400 ppb in total ration.
  - Poultry and swine: ≤20 ppb.

Control measures: Accurate feed testing, quality control, use of feed additives (hydrated sodium calcium aluminosilicate, sodium bentonite), agronomic practices to reduce crop contamination, and chemical treatments (ammoniation or sodium bisulfite).

Conclusion

Aflatoxins are highly toxic to livestock, poultry, and humans. Even non-fatal exposure reduces health and productivity. For dairy cows, aflatoxin levels in feed should not exceed 20 ppb to ensure milk safety. Aflatoxins are among many mycotoxins that negatively impact animal health and production.

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IMPACT OF CLIMATE CHANGE ON FRESHWATER ECOSYSTEMS

ABSTRACT

Freshwater ecosystems—rivers, lakes, wetlands, and groundwater systems—are among the most vulnerable natural systems to climate change. Alterations in precipitation, increasing global temperatures, melting glaciers, and extreme weather events significantly affect water quality, hydrology, and biodiversity (IPCC, 2022). These changes disrupt ecological balance, diminish species diversity, and reduce ecosystem services essential for human well-being, such as drinking water supply, fisheries, and flood regulation (UNEP, 2021). This article examines the major drivers and consequences of climate change on freshwater systems and highlights adaptation and mitigation measures necessary for ensuring long-term ecological resilience.

Keywords: Freshwater, climate change, biodiversity, water quality, ecosystem services.

INTRODUCTION

The United Nations defines climate change as long-term alterations in temperature and weather patterns, largely accelerated by human activities such as industrial emissions, deforestation, and fossil fuel use (UNEP, 2021).

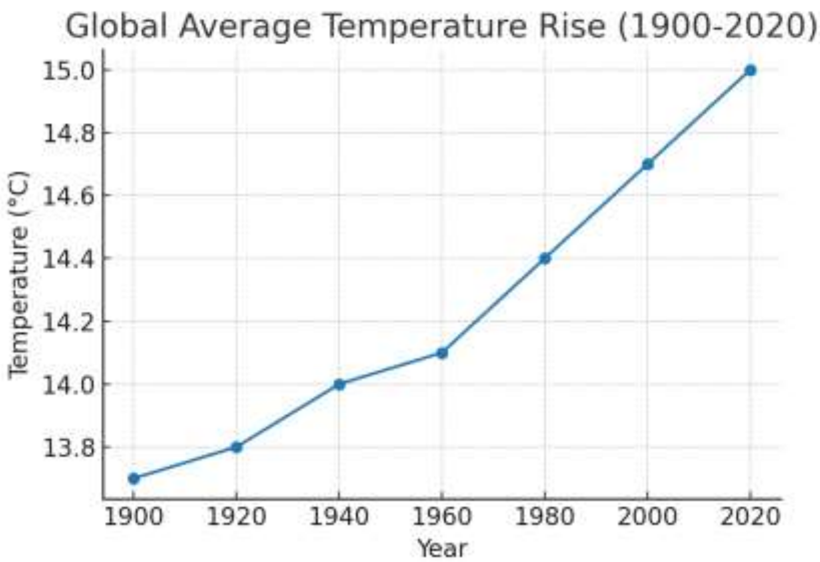

Figure 1: Global average temperature rise over the last century (IPCC, 2022).

Freshwater ecosystems, which make up only 2.5% of the Earth's water resources, are indispensable for life (FAO, 2018). However, they are highly sensitive to climatic variations. As global warming intensifies, the hydrological cycle is being altered, causing shifts in river flows, lake levels, and wetland productivity (IPCC, 2022).

CAUSES OF CLIMATE CHANGE IMPACTS ON FRESHWATER SYSTEMS

1. Natural Causes: Volcanic eruptions releasing aerosols that modify rainfall patterns, variability in solar radiation influencing water temperature, and natural climatic oscillations such as El Niño and La Niña (IPCC, 2022).
2. Anthropogenic Causes: Greenhouse gas emissions increasing global temperatures, large-scale deforestation reducing watershed stability, industrial effluents and agricultural runoffs exacerbating climate-induced water stress, and construction of dams and unsustainable water extraction altering natural hydrology (UNEP, 2021).

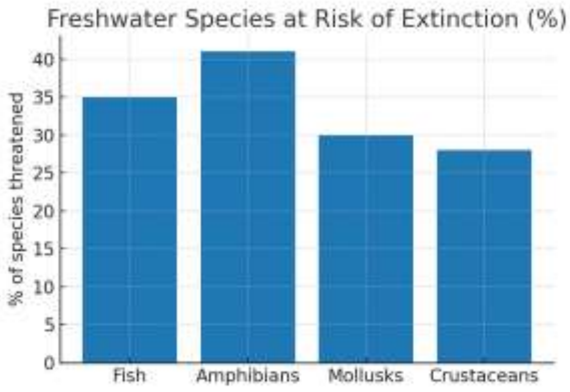

Figure 2: Percentage of freshwater species groups at risk of extinction due to climate change and human pressures (WWF, 2020).

EFFECTS OF CLIMATE CHANGE ON FRESHWATER ECOSYSTEMS

- Rising Temperatures: Warmer waters reduce dissolved oxygen, stressing aquatic organisms and leading to higher fish mortality (IPCC, 2022).
- Altered Hydrology: Irregular rainfall and prolonged droughts reduce river flows and shrink wetlands, affecting migratory species and local livelihoods (UNEP, 2021).
- Biodiversity Loss: Many freshwater species are highly sensitive to thermal and chemical changes, accelerating extinction rates (WWF, 2020).
- Decline in Water Quality: Increased flooding and runoff lead to higher nutrient loading, causing algal blooms and eutrophication (UNESCO, 2019).
- Glacial Melt and Sea-Level Rise: Retreating glaciers reduce freshwater availability, while saline intrusion affects groundwater in coastal regions (IPCC, 2022).
- Food and Livelihood Insecurity: Fisheries and aquaculture sectors are destabilized, directly impacting food supply and rural economies (FAO, 2018).

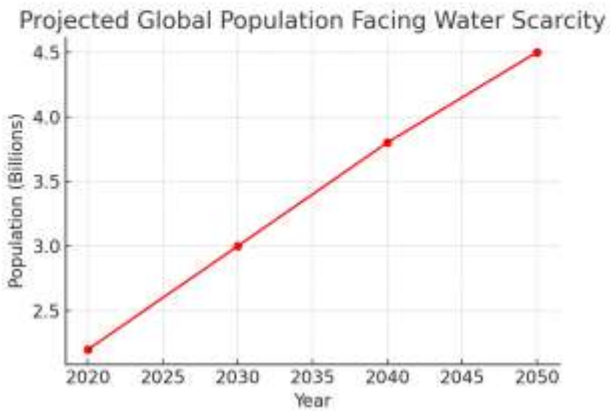

Figure 3: Global projections of populations exposed to water scarcity under climate change scenarios (UNESCO, 2019).

GREENHOUSE GASES AND WATER SYSTEMS

Greenhouse gases such as carbon dioxide, methane, and nitrous oxide not only drive global warming but also influence aquatic chemistry. Methane emissions from wetlands and reservoirs are expected to increase as temperatures rise, further intensifying climate feedback loops (IPCC, 2022).

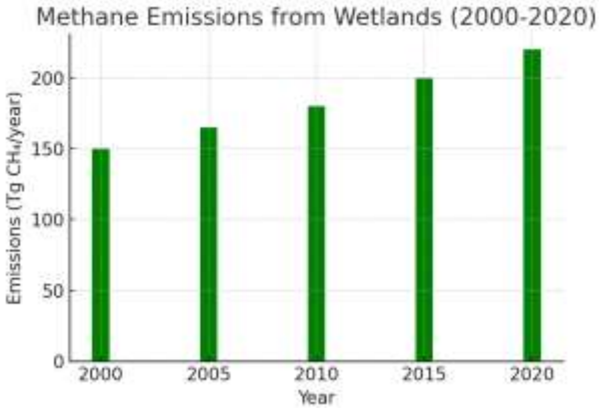

Figure 4: Increasing methane emissions from wetlands under rising temperatures (IPCC, 2022).

ADAPTATION AND MITIGATION STRATEGIES

- Ecosystem-based Adaptation: Restoration of wetlands, riparian vegetation, and floodplains (UNEP, 2021).
- Water Conservation Policies: Efficient irrigation, rainwater harvesting, and groundwater recharge programs (FAO, 2018).
- Pollution Control: Reducing nutrient inflows from agriculture and industry (UNESCO, 2019).
- Climate-resilient Infrastructure: Designing reservoirs and dams to withstand extreme events (IPCC, 2022).
- Research and Monitoring: Continuous biodiversity and hydrological assessments to inform policy (IPCC, 2022).

CONCLUSION

Freshwater ecosystems serve as life-support systems for humans and countless species. Climate change threatens their stability through rising temperatures, altered hydrology, and biodiversity decline (IPCC, 2022). Protecting these ecosystems requires multi-dimensional strategies that integrate research, sustainable water management, and strong policy frameworks. Adaptive measures and greenhouse gas reduction are essential to safeguard freshwater resources for future generations (UNEP, 2021).

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WATERSCAPING: ENHANCING BEAUTY AND SUSTAINABILITY IN MODERN LANDSCAPES

Introduction

Water has always been a central element in landscape design, symbolizing life, purity, movement, and tranquility. From the ancient water gardens of Persia and the grand Mughal gardens of India to contemporary urban parks and residential spaces, water has played a vital role in shaping memorable landscapes. In the modern context, where rapid urbanization, climate change, and environmental stress are pressing concerns, waterscaping has gained renewed importance. Waterscaping not only enhances visual appeal but also contributes to environmental sustainability, microclimate regulation, and human well-being.

Waterscaping refers to the planned and artistic integration of water features into landscape design. It combines aesthetics, engineering, ecology, and horticulture to create functional and attractive outdoor spaces. When properly designed and maintained, waterscaping transforms landscapes into lively, soothing, and ecologically balanced environments.

Concept of Waterscaping

Waterscaping is the art and science of incorporating water as a key design element within a landscape. Unlike simply adding a fountain or pond, waterscaping involves thoughtful planning of water movement, storage, circulation, and interaction with plants, landforms, and built structures.

It treats water as a dynamic component that influences the overall character and performance of the landscape.

A well-designed waterscape considers factors such as site conditions, climate, water availability, purpose of the space, and user experience. The goal is to achieve harmony between water features and other landscape elements such as lawns, trees, flower beds, pathways, and architectural structures.

Types of Waterscaping Elements

1. Ponds and Lakes

Ponds and lakes are still or slow-moving water bodies commonly used in parks, gardens, campuses, and resorts. They may be natural or artificial and often serve as focal points in landscape design. Aquatic plants like lotus, water lilies, and reeds enhance their beauty while helping maintain ecological balance.

2. Fountains

Fountains are among the most popular waterscaping features due to their visual appeal and versatility. They can be formal or informal, traditional or modern. Fountains introduce movement and sound, making spaces more lively and engaging. They are widely used in public plazas, gardens, hotels, and institutional landscapes.

3. Waterfalls and Cascades

Waterfalls and cascades add a dramatic and naturalistic effect to landscapes. The sound of falling water creates a calming atmosphere and masks unwanted noise. These features are often combined with rocks and plants to simulate natural mountain streams.

4. Streams and Rills

Streams and rills are narrow flowing water channels that guide movement through the landscape. They are commonly seen in Mughal and Persian gardens, where water flows through symmetrical channels. In modern landscapes, streams are designed in a naturalistic manner to blend with the terrain.

5. Reflecting Pools

Reflecting pools are shallow, still water bodies designed primarily for visual impact. They reflect surrounding buildings, trees, and skies, creating a sense of openness and elegance. Such pools are frequently used near monuments, museums, and institutional buildings.

6. Rain Gardens and Bioswales

Rain gardens and bioswales are sustainable waterscaping elements designed to manage stormwater. They collect runoff, reduce flooding, and allow water to percolate into the soil. These features combine functionality with aesthetics and are increasingly important in urban landscapes.

Importance of Waterscaping in Landscaping

Aesthetic Value

Water enhances the visual quality of landscapes by introducing reflection, movement, and sparkle. It acts as a focal point and adds depth and contrast to green spaces. Even a small water feature can significantly elevate the overall appearance of a landscape.

Microclimate Regulation

Waterscaping helps regulate temperature through evaporation, creating a cooling effect in hot climates. This is particularly beneficial in tropical and arid regions, where water features make outdoor spaces more comfortable and usable.

Psychological and Social Benefits

The presence of water has a calming and stress-reducing effect on people. The sound of flowing water promotes relaxation and mental well-being. Waterscaped areas often become social spaces where people gather, interact, and spend leisure time.

Environmental Benefits

Waterscaping supports biodiversity by providing habitats for birds, insects, amphibians, and aquatic plants. Sustainable water features improve water quality, recharge groundwater, and reduce surface runoff, contributing to ecological balance.

Waterscaping in Traditional and Modern Landscapes

Traditional Landscapes

Historically, water played a central role in traditional garden styles. Mughal gardens in India featured canals, fountains, and pools arranged symmetrically to symbolize paradise and order. Stepwells, temple tanks, and palace water bodies served both functional and aesthetic purposes.

Modern Landscapes

In contemporary landscapes, waterscaping focuses on sustainability and efficiency. Designers use recirculating systems, solar-powered pumps, and native aquatic plants to minimize water use. Naturalistic designs that mimic wetlands and streams are preferred over rigid formal layouts.

Design Principles of Waterscaping

Successful waterscaping requires careful planning and adherence to design principles. The scale of the water feature should match the size of the landscape. Proper circulation and filtration are essential to prevent stagnation and mosquito breeding. Safety, accessibility, and ease of maintenance must also be considered. Integration with surrounding plants and structures ensures visual harmony.

Maintenance and Management

Regular maintenance is crucial for the long-term success of waterscaping. This includes cleaning debris, managing algae growth, maintaining pumps and filters, and monitoring water quality. Aquatic plants should be pruned periodically to prevent overcrowding. Efficient maintenance ensures that water features remain attractive, hygienic, and functional.

Challenges in Waterscaping

Despite its benefits, waterscaping presents certain challenges. Water scarcity, high installation costs, and maintenance requirements can limit its adoption. Poorly designed water features may lead to water wastage, stagnation, or health issues. These challenges can be addressed through proper planning, use of recycled water, and adoption of sustainable technologies.

Conclusion

Waterscaping is a powerful landscape design approach that combines beauty, functionality, and sustainability. By thoughtfully integrating water features into outdoor spaces, landscapes can be transformed into vibrant, calming, and ecologically balanced environments. When designed and maintained responsibly, waterscaping enhances not only the visual appeal of landscapes but also their environmental performance and human experience. As cities and communities seek greener and healthier spaces, waterscaping stands out as an essential and timeless element of landscape architecture.

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PATIENT-CENTERED HOSPITAL FOOD SERVICES AND EVIDENCE-BASED NUTRITION CARE MODELS IN INDIA

Abstract

Background: Hospital food services in India are transitioning from conventional diet kitchens to more patient-centered, clinically integrated nutrition care systems. However, variation in diet prescription practices, limited nutrition screening, and inadequate dietitian-to-patient ratios continue to affect quality and outcomes.

Objective: To examine current hospital food service practices in India and highlight the shift toward evidence-based, patient-centered nutrition care models that integrate clinical dietitians into multidisciplinary healthcare teams.

Methods: This review synthesizes published research, national guidelines, and hospital case examples to evaluate core components of nutrition service delivery, including diet planning, meal production, quality control, patient feedback mechanisms, and clinical nutrition assessment protocols.

Results: Hospitals that implemented standardized nutrition screening tools, diet orders via EMR, and customized meal planning were reported to have better patient satisfaction and clinical outcomes. Patient-centred menus that take into account cultural preferences in foods and taste acceptability increased meal consumption and minimized plate waste. Nevertheless, issues of personnel training, cross-departmental communication, and resource distribution remain. There is evidence that the presence of dietitians in clinical rounds has a strong potential to enhance nutrition therapy.

Conclusion: Evidence-based, patient-centred models of hospital food services enhance patient recovery and quality of nutritional care. Optimal strategies to scale these models in Indian healthcare would be to strengthen the dietitian workforce, adopt a uniform nutrition system, and formalize meal feedback systems. The policy support, the ongoing professional training, and systematic monitoring of nutrition care outcomes should be stressed in the future.
Keywords: Hospital food service; Clinical dietetics; Patient-centered care; Therapeutic diets; Nutrition screening; Evidence-based practice

Background

Malnutrition is a widespread and severe problem among hospitalized patients in the world, including India, and is linked to poor clinical outcomes, such as higher morbidity, mortality, and extended hospitalization (Goswami et al., 2013; Manjaly et al., 2022). The research conducted in the tertiary care hospitals in India suggests that malnutrition is very high (Goswami et al., 2013). Nutritionally compromised patients are also at risk of healthcare-associated infections (Gupta et al., 2023).

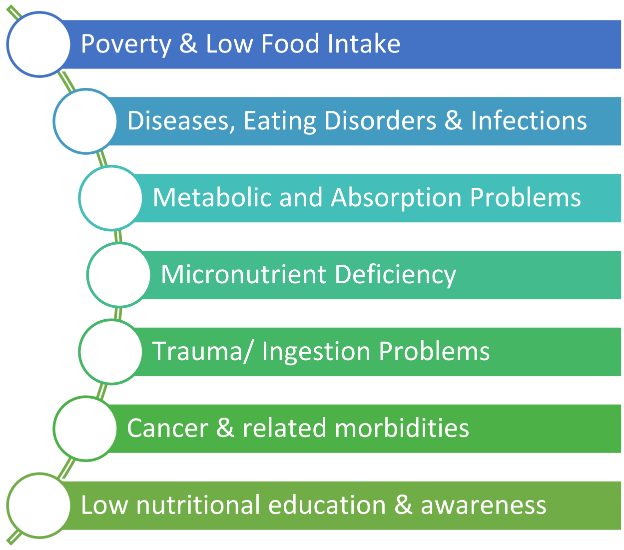

Figure 1: Risk factors that contribute directly or indirectly to the development of malnutrition among hospitalized patients

Proper nutrition is considerably important in treating and recovering hospitalized patients (Sobti et al., 2025). Hospital diets play a crucial role in patient recovery and overall well-being (Muraal and Davar, 2014), and the correct nutritional intake helps to recover faster and lead a better quality of life (Gooch, 2007). Therefore, patient satisfaction with hospital services related to diets is regarded as one of the key indicators of the quality of care offered at Indian hospitals (Arora et al., 2022; Muraal and Davar, 2014). Studies have indicated that, when patients are satisfied, they might respond more to the clinical treatment (Arora et al., 2022).

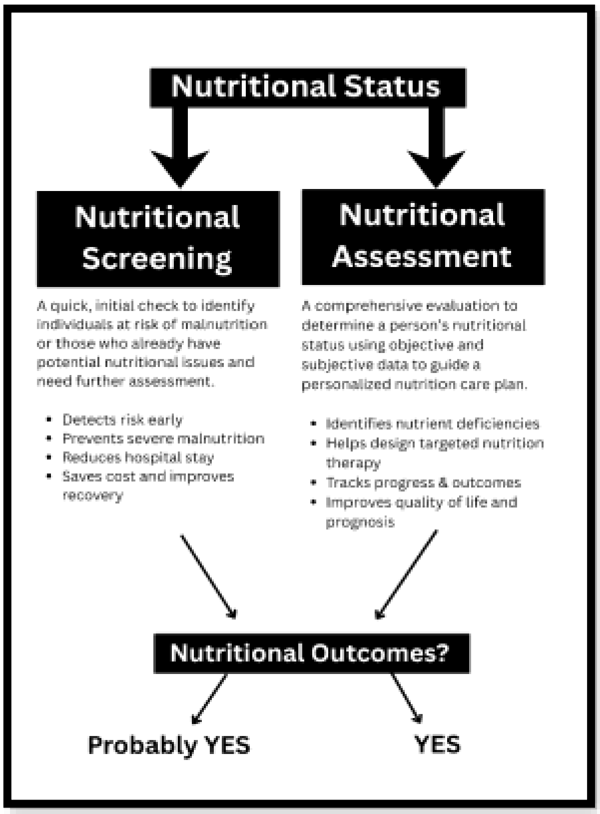

Figure 2: Significance of Evidence-based Nutritional Assessment in hospital

There has been a growing focus on standardized care and evidence-based nutrition practices, as the importance of nutrition to patient outcomes cannot be overstated. One of the most effective approaches to assessing hospitalized adults who are at risk of malnutrition is nutritional risk screening, which involves the use of such a tool as the Malnutrition Universal Screening Tool (as shown in South Indian studies, Mahadevan et al., 2022). Admission screening is vital in early detection of patients at risk and prompt and sufficient nutritional intervention (Arbeloa et al., 2022; Bakshi et al., 2024; Pinho et al., 2021; Reber et al., 2019). The creation and enforcement of national nutritional recommendations based on the local populations are considered important to the proper management of enteral feeding, particularly in severely ill individuals (Alyumni et al., 2023).

Clinical dietitians are useful in enhancing patient outcomes. To illustrate, in India, the guidelines of evidence-based nutrition practices created by dietitians have led to an improvement in clinical indicators in patients diagnosed with type 2 diabetes mellitus (Shanthi et al., 2022). In addition, nutritionist-based initiatives are proven to effectively prevent hospital malnutrition by detecting and intervening early, which results in shortened stay and healthcare costs (Lovesley et al., 2019). The evolution of food services and nutrition care in hospitals is a constant process, and the research carried out in India will focus on determining which factors influence patient satisfaction with their diets and improve the existing practice (Arora et al., 2022).

Objective

The objective of the present study is to examine current hospital food service practices in India and highlight the shift toward evidence-based, patient-centered nutrition care models that integrate clinical dietitians into multidisciplinary healthcare teams.

Results

In India, there are a number of positive results reported in hospitals that have switched to patient-centered and evidence-based nursing care models. The use of standardized nutrition screening tools, diet orders based on EMR, and patient-specific meal planning has been associated with increased patient satisfaction and clinical outcomes. An example is that the electronic bedside meal ordering systems could have a positive effect on patient diet, satisfaction, plate waste, and cost relative to standard menus (MacKenzie-Shalders et al., 2020). Electronic Medical Records proved to be a significant improvement in the completeness of diet documentation (Wurster et al., 2023).

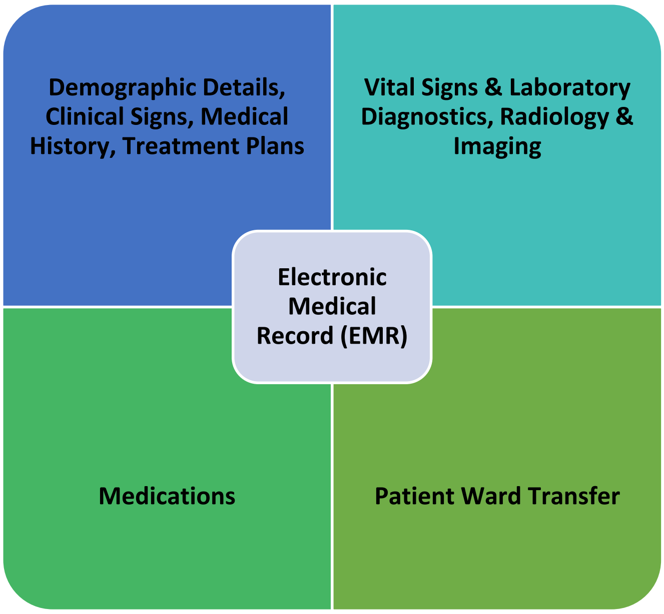

Figure 3: Features of Electronic Medical Record

Patient-focused menus, which were created with references to the cultural preferences in food and taste acceptability, were identified to improve the meal consumption and decrease the waste on the plate (Muraal and Davar, 2014; Uddin et al., 2023). Satisfaction rates of patients with dietary services are one of the most significant quality care indicators, and satisfied patients will have a higher likelihood of positively reacting to clinical treatment (Arora et al., 2022). Good presentation, temperature of serving meals, and distribution of meals on time are some of the factors that affect the satisfaction of patients with hospital food services (Gooch, 2007; Muraal & Davar, 2014).

Although these have been improved, there are a number of challenges that still exist in the hospital food services. These are challenges in training of the staff, interdepartmental coordination, and resource allocation. Another set of hurdles, which are perceived by food handlers, includes insufficient human and material resources, insufficient periodical training, and the absence of management focus on dietetic services (Bertin et al., 2009). Other challenges include deficits in hospital foodservice management systems, patient meal experiences, and inadequate staff involvement in the solution of food waste and improvement of patient meal care (Manimaran et al., 2025).

Inclusion of clinical dietitians in multidisciplinary healthcare teams has greatly enhanced the results of nutrition therapies. Early nutrition risk identification and intervention programmes run by dietitians have been demonstrated to reduce the length of stay and healthcare expenditures in hospitals (Lovesley et al., 2019). Interdisciplinary healthcare teams play a crucial role in the proper management of nutrition, which facilitates the communication and cooperation of different professionals (Alzahrani et al., 2024).

Discussion

The results highlight the drastic shift in Indian hospital food services to more patient-centered and evidence-based services. These innovative methods can be proven to be effective by the positive association between standardized nutrition protocols, EMR integration, and individualized meal planning, and better patient satisfaction and clinical outcomes. This change is connected to the fact that optimal nutrition is a component of patient recovery and the quality of the hospital care as a whole (Sobti et al., 2025).

The importance of cultural preferences and food taste when designing the menu cannot be underestimated, as it directly determines the food intake and reduces the wastefulness, becoming a common characteristic in hospital restaurants (Muraal and Davar, 2014). Patient satisfaction of patients is a very important indicator of good dietary services, which implies that hospitals should always review and react to their services to match patient expectations and clinical demands (Arora et al., 2022).

Nevertheless, the challenges in staff training, interdepartmental coordination, and resource allocation that were identified mean that the full implementation of these patient-centered models will require systemic changes. The attitudes of food handlers towards the shortage of resources and training deficiencies indicate that they should receive more administrative assistance and invest in the dietetics department. The solution to these problems (optimization of meal order systems, communication, and continuous staff training) is necessary to minimize food waste and enhance the quality of care of patients with meals (Manimaran et al., 2025). It is impossible to overestimate the significance of clinical dietitians in multidisciplinary teams. Their intervention, starting with screening on nutrition in early stages (Arbeloa et al., 2022; Bakshi et al., 2024; Pinho et al., 2021; Reber et al., 2019) and continuing with adhering to evidence-based nutrition practice guidelines, directly leads to improved patient outcomes and cost-efficiency (Lovesley et al., 2019; Shanthi et al., 2022). This supports the importance of improving dietitian staffing and interprofessional cooperation to make sure that all at-risk patients get nutritional assistance on time and effectively (Alzahrani et al., 2024; Santy-

Tomlinson et al., 2021).

Conclusion

The shift of the hospital food services in India towards the process of patient-centered and evidence-based nutrition care models is a significant step towards improving the patient outcomes (Sobti et al., 2025). Active integration of standardized nutrition screenings, EMR-based diet orders, and personalized meal planning has been shown to result in positive patient satisfaction and clinical recovery (MacKenzie-Shalders et al., 2020; Wurster et al., 2023). Besides, special attention to culturally sufficient and tasty menus has also proven to increase the consumption of meals and reduce the volume of waste (Muraal and Davar, 2014; Uddin et al., 2023).

Even though these positive changes have been introduced, they still have certain challenges, particularly in the aspects of staff training, interdepartmental integration, and resource distribution of hospital food services (Bertin et al., 2009; Manimaran et al., 2025). The solution to these systemic issues should involve the increase of administrative support, investing in dietetics, and continued staff growth, which is critical to the optimal functioning of such advanced models (Manimaran et al., 2025).

The role of clinical dietitians in multidisciplinary healthcare teams cannot be underestimated as they assist in enhancing patient outcomes, such as early nutritional screening (Arbeloa et al., 2022; Bakshi et al., 2024; Pinho et al., 2021; Reber et al., 2019), the implementation of the evidence-based practice guidelines (Shanthi et al., 2022), which, in turn, results in better patient outcomes and cost-efficiency (Lovesley et al.,). The workforce of dietitians has to be strengthened, and interprofessional collaboration should be encouraged to ensure that all hospitalized patients at risk of malnutrition receive all-encompassing and effective nutrition support (Alzahrani et al., 2024; Santy-Tomlinson et al., 2021).

Finally, these patient-centered, evidence-based models need long-term efforts to be scaled to the Indian healthcare environment. Continuous improvement of the quality of nutritional care and patient recovery in India will be dependent on policy support, continuous professional education of all the food service professionals, and systematic monitoring of the results of nutrition care.

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A SUSTAINABLE BIOENGINEERING TOOL FOR WATER TREATMENT, SOIL AND WATER CONSERVATION

INTRODUCTION

The Vetiver System (VS) was first created by the World Bank in 1985 to protect soil and water resources in India. Over the years, it has become a well-known, eco-friendly bioengineering technology used around the world. The system plays a significant role in managing agricultural land, protecting the environment, conserving soil and water, stabilizing infrastructure, managing contamination, and treating water and wastewater.

Vetiver grass (*Chrysopogon zizanioides*), a perennial plant native to South India, can grow and thrive in tough environmental conditions. While it is a tropical grass, it can tolerate extreme temperatures, including frost. During frost, the above-ground parts may die back or go dormant, but the underground growing points stay alive and active, allowing for quick regrowth when conditions improve.

Vetiver is a C4 plant with unique physical and functional traits, such as a specialized stomatal structure, specific skin features, and a distinct cellular arrangement compared to other C4 plants. These traits contribute to its high efficiency in photosynthesis and water use, as well as its ability to withstand stress from drought, salinity and temperature extremes. These adaptations are believed to be crucial for vetiver's success in damaged and polluted environments.

Phytoremediation is the use of plants to break down, absorb, stabilize, or immobilize contaminants in soil and water. Vetiver grass is among the most effective plants for phytoremediation, thanks to its deep roots, fast growth, and strong tolerance to toxic substances. The phytoremediation process with vetiver is non-intrusive, affordable, visually appealing, and environmentally friendly, making it especially good for large-scale cleanups of polluted areas.

ROLE OF VETIVER IN WATER TREATMENT

Morphological Attributes

Vetiver grass has a deep, fast-growing, fibrous root system that can reach several meters into the soil. This wide root network improves soil moisture absorption, enhances drainage and stabilizes soil structure.

Tall, sturdy shoots of vetiver can grow up to three meters high forming dense hedges that act as natural filters. These hedges slow water flow, reduce runoff speed and encourage sediment settling.

Physiological Attributes

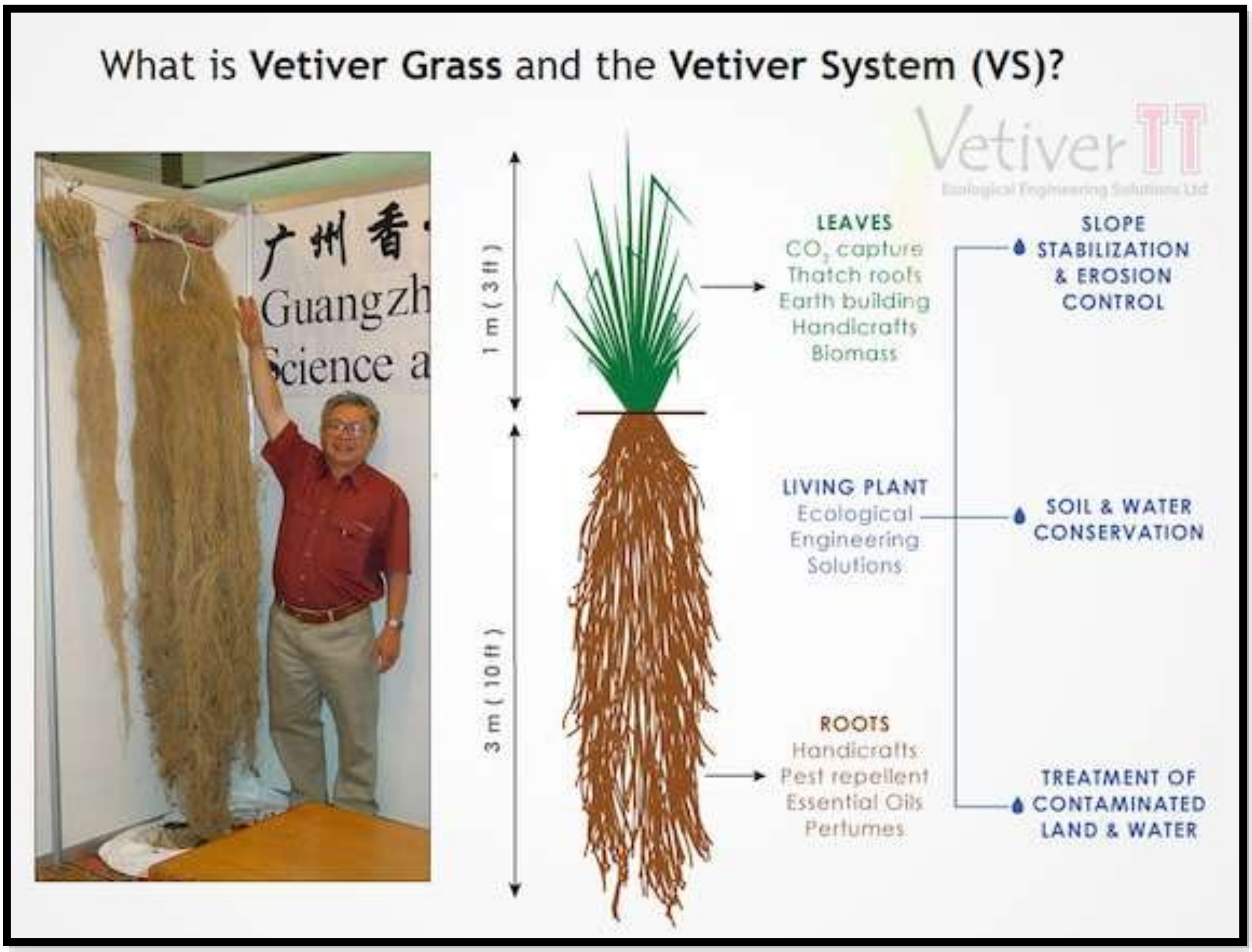
Vetiver shows remarkable strength against various poor soil and water conditions, including high acidity, alkalinity, salinity, sodicity, magnesium toxicity and heavy metal pollution. It effectively takes up dissolved nutrients like nitrogen and phosphorus from polluted water which helps decrease nutrient buildup and eutrophication. In addition, vetiver is resistant to many herbicides and pesticides and can break down organic compounds linked with these chemicals.

Wastewater Management Applications

Vegetative treatment systems using vetiver are among the few realistic methods for reducing or eliminating large volumes of wastewater. Vetiver has effectively been used for:

- Disposing of septic tank effluent
- Treating municipal and industrial wastewater
- Reducing nutrient and contaminant levels in agricultural runoff

In landfill sites, leachate management is a significant environmental issue due to heavy metals and various pollutants. Vetiver's vigorous



growth allows it to absorb high amounts of contaminants. Often, its water needs during dry times surpass the amount of leachate produced, helping lower leachate buildup.

Retention of Agro-chemicals and Sediments

Vetiver hedges along drainage lines act as natural barriers that capture debris, sediments, and agro-chemicals in agricultural areas. The thick stems close to the ground gather soil particles and organic matter carried by runoff water, preventing pollution off-site. This retention of nutrients boosts soil fertility and safeguards downstream water sources.

Salinity and Sodicity Tolerance

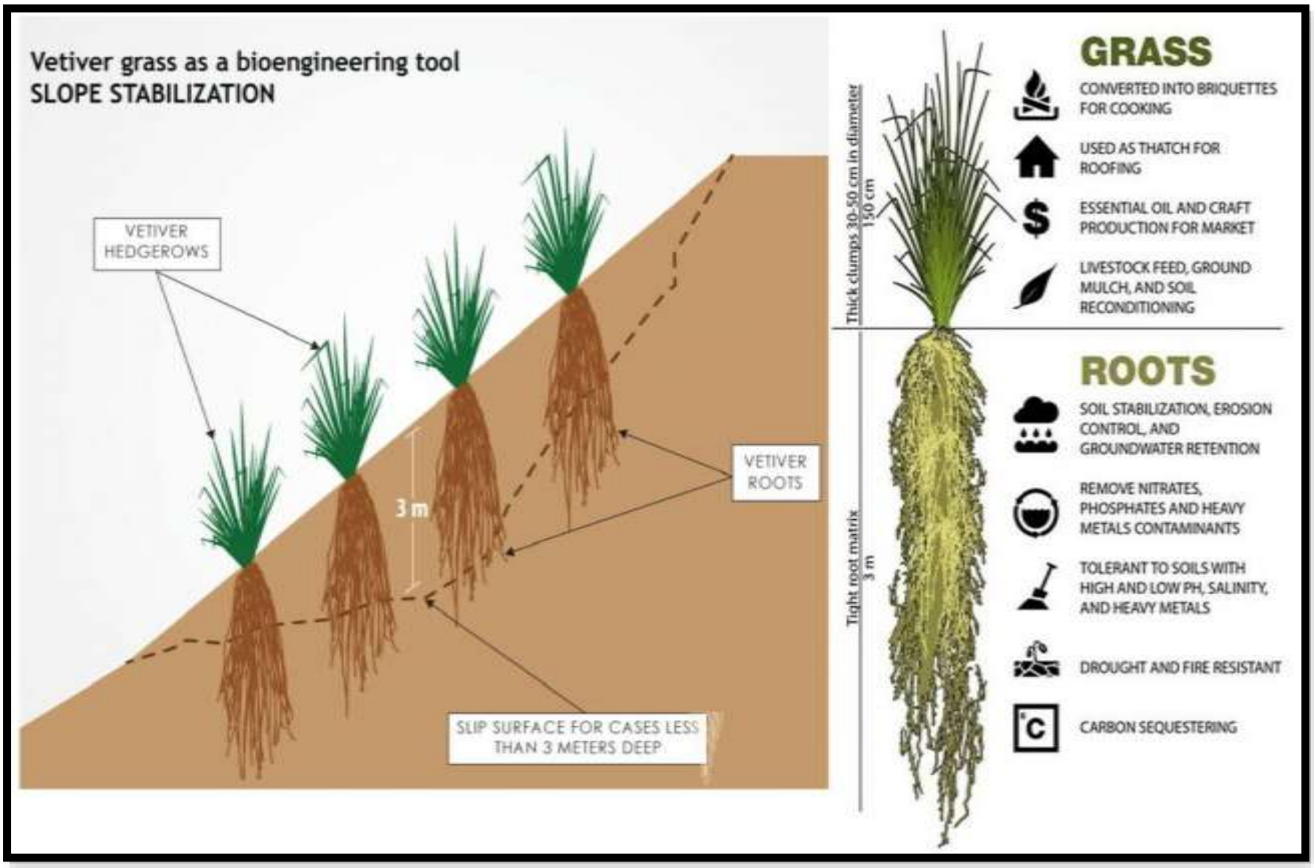
Vetiver tolerates saline and sodic soils very well, with a salinity limit of $EC_{se} = 8\ dS\ m^{-1}$. This makes it comparable or better than many salt-tolerant crops and pasture species, making it suitable for reclaiming salt-affected lands and treating saline wastewater.

SOIL AND WATER CONSERVATION

Soil conservation practices aim to manage or lessen soil erosion caused by water and wind. Water erosion happens when soil particles detach and get carried away by excessive runoff. Wind erosion arises from strong winds near the soil surface. Vegetative barriers like vetiver hedges along with contour banks and diversion channels are commonly used to reduce both types of erosion.

The main idea behind vetiver-based conservation systems is to lower water and wind speed. By slowing down runoff and wind vetiver effectively reduces soil detachment and transport helping to save soil and water resources.

Unique Characteristics of Vetiver for



Conservation

The success of vetiver in soil and water conservation can be linked to the following unique qualities:

- A deep, massive, and fibrous root system that keeps the soil together
- Erect and firm stems that create dense hedges, minimizing the erosive power of flowing water
- High tolerance to tough soil conditions, including acidic, alkaline, saline, sodic and acid sulphate soils
- Ability to endure long periods of flooding and submersion
- Adaptability to various climates, from cold mountainous areas to dry coastal regions
- Easy vegetative propagation, making establishment and upkeep cost-effective

Flow-Through Erosion Control Mechanism

When planted along slopes, vetiver acts as a living barrier, slowing surface runoff while allowing water to filter through. This "flow-through" erosion control method gives water time to infiltrate, reduces sediment movement, and safely redistributes excess runoff. Vetiver hedges also shield the soil surface from direct raindrop impact, a key factor in erosion.

CONCLUSION

Vetiver grass (*Chrysopogon zizanioides*) offers a functional, sustainable, and cost-effective solution for treating water, conserving soil and water, and protecting the environment. Its unique physical and functional traits allow it to perform well under harsh conditions where other plants struggle. The Vetiver System provides a nature-based approach that combines ecological recovery with farming productivity and infrastructure protection, making it a valuable resource for managing land and water sustainably.

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ROLE OF ORGANIC MANURE IN CEREAL-PULSES INTERCROPPING SYSTEM

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Introduction

Intercropping, a multifaceted form of intensive cropping aimed at boosting production, offers advantages such as more efficient land use, reduced soil erosion, support for farmers during years when the main crop fails and improvements in soil fertility and overall crop yield. Systems that combine cereals and legumes consistently out perform sole cropping and other cropping patterns because legumes contribute biological nitrogen fixation, providing an added benefit.

Cereal–legume intercropping is the legume's ability to fix atmospheric nitrogen, converting it into a form plants can use. This nitrogen supports the legume's growth and can also be released into the soil for nearby crops. The symbiotic interaction between cereals and legumes improves soil fertility and offers a cost-effective option for resource-poor farmers. Compared to sole cropping, legume intercrops provide several socioeconomic as well as biological and ecological advantages.

Manure is a type of organic material produced by the decomposition of animal dung, crop leftovers and fruit and vegetable peels. After it breaks down, it supplies a variety of nutrients that plants need. It is a completely natural and chemical-free substance that not only increases crop yields but also enhances the soil's productivity. The practice of making manure is very old and widely used by farmers. In the past, farmers often used chemical fertilizers to try to achieve the highest possible crop production. However, today they are placing greater importance on natural fertilizers instead of chemical ones. This is because long-term use of chemical fertilizers has harmed the land: although they boost crop yields, they have also led to more pest and disease problems in cereals. For this reason, most farmers now prefer natural fertilizers over chemical fertilizers.

Characteristics of Organic Manures

- Organic manures are generally **bulky and rich in organic material**, though they also contain plant nutrients in smaller amounts. When these manures are added to the soil, they have several beneficial effects:
- They provide essential **primary, secondary and micronutrients** to plants. These nutrients become available as soil microorganisms break down the organic matter through the process of mineralization.
- The organic matter in the manures improves soil physical properties, such as **soil structure, aeration and water-holding capacity**, which enhances overall soil quality.
- By supplying energy sources for soil microbes, organic manures **stimulate microbial activity**, further supporting nutrient cycling and soil health.
- They also enhance the soil's **buffering capacity and cation exchange ability**, helping to stabilize soil pH and influence the availability of minerals and nutrients within the soil.

Benefit of organic manure

- **Provides essential nutrients to plants:** Manure supplies important plant nutrients, which become available as organic matter decomposes and releases them slowly for plant uptake.
- **Enhances soil physical and chemical properties:** The addition of organic manure improves soil structure, increases water-holding capacity, and enhances overall soil fertility and texture.
- **Boosts soil micro- and macro-organisms:** The organic material acts as food for beneficial microorganisms and soil fauna, increasing their population and activity, which supports nutrient cycling and soil health.
- **Restores soil fertility and soil health:** Regular manure application helps rebuild organic matter, improving long-term fertility and the biological functioning of the soil.
- **Improves soil moisture retention:** Organic matter enhances the soil's ability to retain moisture, keeping it moist for longer periods and reducing drought stress.
- **Improves aeration and water movement:** Manure improves soil porosity and structure, which allows better air exchange and water infiltration throughout the soil profile.
- **Increases crop yield and quality:** By improving nutrient availability, soil structure and biological activity, manure application often leads to higher crop yields and improved produce quality.

Role of Organic Manure

1. Organic manure serves as a natural source of food for plants.
2. It releases nutrients slowly over time, ensuring their continuous availability throughout the growing season.
3. The application of organic manure improves and sustains soil fertility and overall soil health.
4. It helps bind soil particles together, forming stable soil aggregates and improving soil structure.
5. Organic manure enhances water infiltration and percolation within the soil profile.

6. The granular nature of soil is improved, creating favorable conditions for aeration and permeability.
7. It plays an important role in regulating soil temperature.
8. The water-holding capacity of soil is significantly increased by organic manure.
9. Organic manure enhances the buffering capacity of soil, helping to stabilize soil pH.
10. Both the physical and biological properties of soil are improved through the use of organic manure.
11. By increasing soil porosity, organic manure facilitates proper air circulation within the soil.
12. Organic mulching moderates soil temperature by keeping soils cooler in summer and warmer during winter.
13. It helps in reducing soil alkalinity.
14. Organic manure improves phosphorus availability to plants in acidic soils.
15. Overall, organic manure positively influences soil properties and crop growth.

Physical properties of soil: The application of organic manure greatly affects several soil physical properties such as bulk density, porosity, soil structure and water holding capacity which in turn play a crucial role in soil health and agricultural productivity (Verma *et al.*, 2024).

Chemical properties of soil: Across the world, growing quantities of chemical fertilizers have been used in agroecosystems, leading to significant declines in soil physicochemical quality and reduced productivity. In contrast, organic fertilizers sourced from plant and/or animal materials can enhance soil physicochemical conditions due to their rich organic matter content and more balanced nutrient supply (Cui *et al.,* 2018).

Biological properties of soil: While integration with organic manures and biofertilizers would be able to preserve soil fertility and prolong crop output, applying all the necessary nutrients through chemical fertilizer had a detrimental effect on soil fertility and resulted in unsustainable yields. Organic manures are thought to be beneficial for enhancing the soil's nutritional and physical conditions as well as increasing soil microbial activity. In addition to enhancing the soil's qualities, they significantly increase the amount of important nutrients in the soil. Additionally, the breakdown of organic matter in the soil produces a variety of biological responses that aid in the prevention of numerous pathogens that cause disease (Ramesh *et al*., 2010).

Sustainable soil management is vital for global food security, environmental protection, and ecosystem resilience. Modern farming often degrades soil, reducing its fertility and long-term productivity. This has increased interest in alternative practices like using organic manures, which can improve soil health, enhance nutrient cycling, and reduce reliance on chemical fertilizers. Derived from plant and animal materials, organic manures enrich the soil with organic matter, nutrients, and beneficial microorganisms. Understanding their effects on soil properties is key to optimizing their role in sustainable agriculture. (Verma et al., 2024)

Farmyard manure (FYM) also plays an important role in supporting beneficial bacteria, which help make nutrients available to crops. Most crops take up nitrogen in the form of nitrate, and this form is produced through the action of soil bacteria (Grzyb *et al*., 2021).

Yield and Yield attributes: The application of 5 t/ha vermicompost has shown significantly higher maize dry forage, mung dry forage, maize protein and mung protein in were observed (Niazi *et* al., (2017).

The highest number of pods per plant was observed in the 2:2 wheat + chickpea intercropping system with application of Organic treatment FYM 5 t ha + poultry manure 2 t ha + *Azotobacter*+ PSB (Raju *et al.*, 2025).

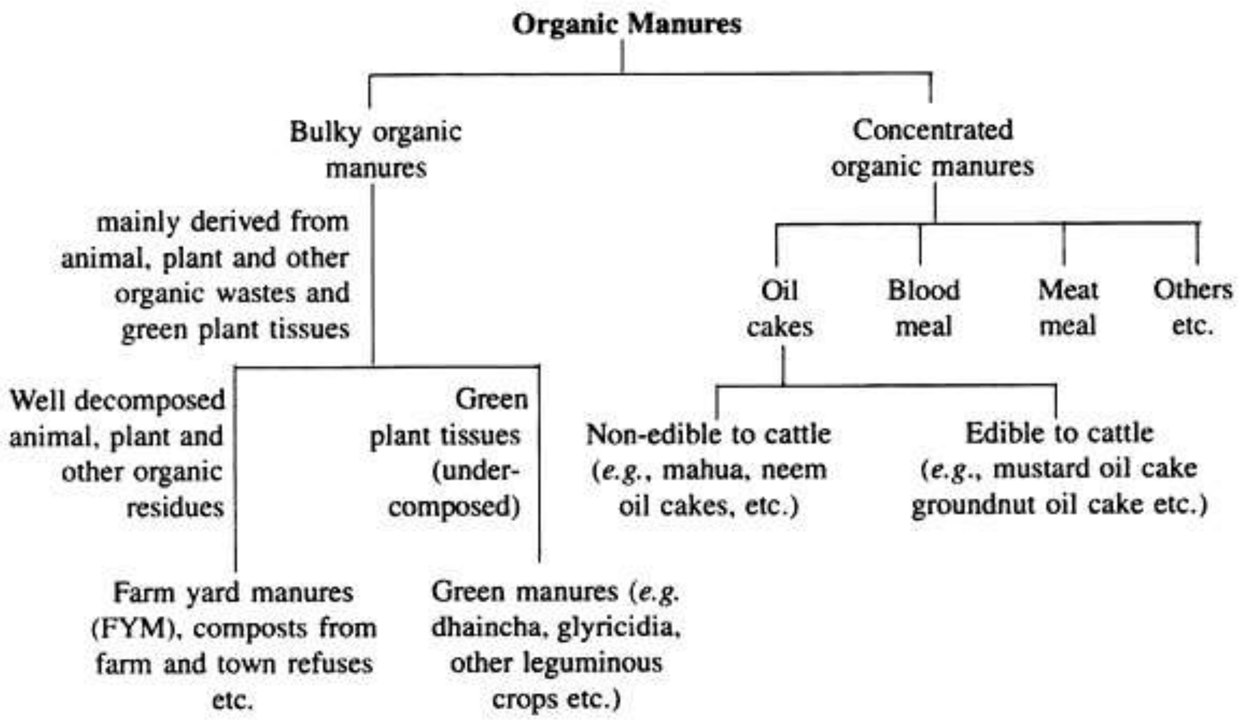
The Number of pods per plant, pod length and number of seeds per pod were recorded significantly higher under 10t/ha FYM and three spray of banana pseudostem sap (Kokani *et al.,* 2025).

Classification of Organic Manure

1. Bulky Organic manure

Farm Yard Manure (FYM) is a type of bulky organic manure made from a mixture of cattle dung, urine, bedding materials, and crop residues. Unused fodder and household wastes like ash are also added. These materials are collected in pits or heaps, usually in a corner of the farmyard, where they are left to decompose naturally. After about three to four months, the material turns into well-rotted compost, which is then applied to fields. Properly decomposed FYM typically contains about **0.5% nitrogen (N), 0.2% phosphorus (P_2O_5), and 0.5% potassium (K_2O)**. (TANU, 2016).

Sheep and Goat Manure:
Manure obtained from the feces of sheep and goats is rich in nutrients and is often more



concentrated than other organic manures. On average, it contains about **3% nitrogen (N), 1% phosphorus (P_2O_5), and 2% potassium (K_2O)**, making it highly beneficial for improving soil fertility.

Poultry Manure: Poultry manure is derived from the droppings of birds and decomposes very quickly. If it is left exposed, nearly **50% of its nitrogen can be lost within 30 days**. Compared to other bulky organic manures, poultry manure is particularly rich in nitrogen and phosphorus. Its average nutrient composition is **1.2% nitrogen (N), 1.4% phosphorus (P_2O_5), and 0.8% potassium (K_2O)**.

Table 1: - Nutrient content in bulky organic manure

No	Manure	N (%)	P_2O_5 (%)	K_2O (%)
1	FYM Manure	0.5	0.2	0.5
2	Sheep Manure	0.8-0.9	0.35	1
3	Compost Manure	0.5-0.1	0.4-0.8	0.8-1.2
4	Poultry Manure	1.2-1.8	1.4-1.8	0.8-0.9

Katyayan, A. (2019)

Concentrate Organic Manure:

Oilseed Cakes: After oil is extracted from oilseeds, the remaining solid residue is dried and formed into cakes, which are used as organic manure. These oilseed cakes are rich in nutrients and help improve soil fertility. There are two main types of oilseed cakes.

1) Edible Oil Cakes: Edible oil cakes are non-toxic and can be safely fed to livestock. Examples include **groundnut (peanut) cake and coconut cake**. When used as manure, they supply nutrients to the soil and enhance crop growth.

Table 2: - Nutrient Content in Concentrate Organic Manure

No	Manure	N (%)	P_2O_5 (%)	K_2O (%)
1	Safflower	7.9	2.2	1.9
2	Peanut	7.3	1.5	1.3
3	Till	6.2	2.0	1.2
4	Mustard	5.2	1.8	1.2

Sathyamarayana, *et al.* (2020)

2) **Non-edible Oil Cakes:** Non-edible oil cakes are not safe for animal consumption due to the presence of toxic substances. However, they are highly valuable as

organic manures. Common examples include **castor cake, neem cake, and mahua cake**. These cakes supply nutrients to the soil and also help in improving soil health; neem cake, in particular, has pest-repellent properties.

Table 3:- NPK % present in different Oil Cakes

No	Manure	N (%)	P_2O_5 (%)	K_2O (%)
1	Neem	5.2	1	1.4
2	Castor	4.3	1.8	1.3
3	Karanj	3.9	0.9	1.2
4	Mahua	2,5	0.8	1.8

Sathyamarayana, *et al.* (2020)

Intercropping:

Intercropping is define as a growing of two or more crops simultaneously on the same piece of land with or without row arrangement.

Types of Intercropping:

1. Row intercropping: Row intercropping refers to the practice of growing two or more crops together in distinct rows, either within the same field or alongside one another, while maintaining the normal row arrangement of the main crop. It is widely adopted as an effective technique to enhance overall productivity and ensure efficient use of land, nutrients, light, and water.

2. Mixed intercropping: Growing two or more crops simultaneously on the same land without following a fixed row arrangement is referred to as mixed intercropping, also known as mixed cropping. A common example of this practice in pasture-based cropping systems is grass–legume intercropping.

3. Strips intercropping: Strip intercropping involves cultivating two or more crops in adjacent strips, particularly on sloping soils, and has been found to enhance radiation use efficiency, especially in marginal and resource-poor areas.

4. Relay intercropping: In this system,

the second crop is sown after the first crop has completed a substantial part of its growth cycle and has either entered the reproductive stage or is close to maturity but not yet ready for harvest.

Based on percent of plant population, intercropping is divided into two types:

1. Additive series
2. Replacement series

Advantages of Intercropping

- Increasing production
- Greater use of environmental resources
- Reduction of pest, disease and weeds damage
- Stability and uniformity yield
- Improve soil fertility and increase in nitrogen

CONCLUSION:

From the foregoing discussion, it can be concluded that application of Organic manure in cereal–pulse intercropping systems improves soil health, nutrient availability and crop productivity. The combined use of organic manures with reduced inorganic fertilizers enhances yield, quality and profitability while sustaining soil physical, chemical and biological properties, making the system environmentally and economically sustainable

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HIGH-DENSITY PLANTING (HDP) IN PAPAYA

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Introduction

Papaya (*Carica papaya* L.) is a fast-growing, high-value fruit crop widely cultivated in tropical and subtropical regions. Traditional papaya cultivation uses wider spacing, which often underutilizes land, light, and inputs. High Density Planting (HDP) is an improved cultivation approach that involves planting a greater number of papaya plants per unit area with optimized spacing, nutrient management and canopy control. The introduction of HDP in papaya aims to increase productivity per hectare, ensure early and higher economic returns, and improve resource-use efficiency such as water, fertilizers, and sunlight. With the availability of dwarf or semi-dwarf varieties, drip irrigation, fertigation, and better crop management practices, HDP has become a practical and profitable option for farmers. When properly managed, HDP can lead to uniform growth, better fruit quality, and higher total yield, making it an important strategy for sustainable and commercial papaya production.

(High Density Planting of Papaya Orchard)

What is High Density Planting in Papaya?

In traditional papaya cultivation, spacing is usually wide (about 1.8 m × 1.8 m), resulting in fewer plants per hectare.

In High Density Planting, spacing is reduced (such as 1.2 m × 1.2 m or 1.5 m × 1.2 m), allowing more plants per hectare without reducing fruit quality when managed well.

Objectives of High Density Planting

- Increase yield per unit area
- Obtain early and higher income
- Efficient use of land, water, and nutrients
- Uniform plant growth and fruiting
- Better suitability for commercial farming

Plant Spacing and Plant Population

System	Spacing	Plants per hectare (approx.)
Traditional	1.8 m × 1.8 m	3,000
HDP	1.5 m × 1.2 m	5,500
Ultra HDP	1.2 m × 1.2 m	6,900

(Note: Variety, soil fertility, and climate influence the ideal spacing.)

Suitable Varieties for HDP

Recommended varieties:

- Red Lady 786
- Arka Surya
- Arka Prabhat
- Pusa Dwarf
- Pusa Nanha
- CO-8

These varieties have:

- Short internodes
- Compact canopy
- Early flowering and fruiting

Land Preparation

- Deep ploughing (2–3 times) to loosen soil
- Well-drained sandy loam or loam soil is ideal
- Incorporate FYM (10–15 kg per pit)
- Raised beds are recommended in high rainfall areas

Pit size:

- 45 × 45 × 45 cm

Nutrient Management (Very Important in HDP)

Since more plants are grown, nutrient demand is higher.

Fertilizer Schedule (per plant per year):

- Nitrogen (N): 250 g
- Phosphorus (P_2O_5): 250 g
- Potassium (K_2O): 500 g

Apply fertilizers in split doses at monthly intervals.

Fertigation (drip irrigation + fertilizers) is strongly recommended for HDP.

Irrigation Management

- Drip irrigation is best for HDP
- Frequent but light irrigation
- Avoid waterlogging (papaya roots are sensitive)

Benefits of drip in HDP:

- Saves water
- Improves nutrient use efficiency
- Reduces disease incidence

Canopy and Plant Management

- Remove weak, diseased, or excess plants early
- Maintain single healthy plant per pit
- Remove lower yellowing leaves regularly

- Ensure good sunlight penetration

Flowering, Sex Expression & Pollination

- Papaya plants may be male, female, or hermaphrodite
- Hermaphrodite plants are preferred for commercial HDP
- Rogue out excess male plants (retain about 1 male for 10–15 plants if needed)

Pest and Disease Management

High density increases humidity, so disease control is critical.

Common problems:

- Papaya ringspot virus
- Powdery mildew
- Root rot
- Aphids and whiteflies

Management:

- Use virus-free seedlings
- Control insect vectors
- Maintain field sanitation
- Ensure proper spacing and aeration

Yield Advantages of HDP

Parameter	**Traditional**	**HDP**
Yield/plant	Higher	Slightly lower
Yield/hectare	Moderate	Very high
Crop duration	Longer	Shorter
Profit	Moderate	High

(Average yield under HDP can reach 80–100 tonnes/ha, compared to 40–50 tonnes/ha in traditional planting.)

Advantages of HDP

- Higher productivity per hectare
- Early fruiting and harvesting
- Better land utilization
- Suitable for small landholders
- Higher net returns

Limitations of HDP

- Requires intensive management
- Higher initial cost
- Greater risk of disease if mismanaged
- Needs regular monitoring and skilled practices

Conclusion

High Density Planting of papaya is a profitable and efficient system when combined with:

- Suitable varieties
- Proper spacing
- Balanced nutrition
- Drip irrigation
- Timely pest and disease management

It is especially beneficial for commercial papaya cultivation in tropical and subtropical regions

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Genetic improvement of Albizias *in India*

Abstract

Genus Albizia comprises several multipurpose tree species which are of highly economic and social importance distributed throughout India. It has wider applicability due to wider utility for timber, fodder, fuelwood, and agroforestry. This review highlights the current status of genetic improvement, patterns of natural genetic diversity, and the suite of conventional and molecular tools employed to date for Indian Albizias. Reviews of literature hints towards considerable inter- and intraspecific variation, limited provenance trials, sparse genomic resources, fragmented germplasm collections and few coordinated breeding programmes.This article addresses addressing capacity, funding and coordination gaps can transform Albizia improvement from opportunistic efforts to sustained, impact-oriented programmes supporting restoration and rural livelihoods.

Keywords: Albizia, genetic improvement, provenance trials, strategies, untapped.

1. Introduction

Trees of the genus *Albizia* (Fabaceae: Mimosoideae) are fast-growing, nitrogen-fixing, multipurpose species with substantial ecological and economic value in India. They are used in agroforestry, afforestation, horticulture (shade, ornamentals), fodder, fuelwood, medicinal uses and reclamation of degraded lands. Despite wide planting and usefulness in agroforestry, systematic tree breeding program on Albizia is still lagging behind major plantation species like Eucalyptus and Acacia. At present the farmers of Haryana, Punjab, Western Uttar Pradesh and parts of Uttarakhand preferening on exotic species Eucalyptus and Poplar for agroforestry (Bijalwan *et al*., 2014). This article aims to provide a baseline roadmap and formulate strategies for genetic improvement of this genus.

2. Biology and breeding behavior

Albizia species are mostly outcrossing (entomophilous or anemophilous pollination depending on species) with high heterozygosity and often show strong genotype × environment interactions. Important biological considerations for breeding programs:

Flowering phenology: asynchronous flowering across provenances — affects controlled pollination and seed production.

Seed biology: many *Albizia* species produce orthodox seeds with variable storage behaviour; understanding seed storage and dormancy is critical for seed systems (Sivakrishnan and Swamivelmanickam, 2019).

3. Usage of Albizias

Albizia species are socially very essential for the production of significant fodder, high quality timber and a valuable resource for gum yield. (Joycharat, 2014).

3.1Medicial use

Albizia julibrissin, A. lebbeck, A. procera and *A. amara* are important in ayurvedic medicine .Seeds of *A. lebbeck* are astringent and given in piles and restorative tonic, roots powdered in making strong gums, leaves in night blindness (Singh, 1995). Seeds are astringent and given in piles and restorative tonic, roots powdered in making strong gums, leaves in night blindness (Singh, 1995).

3.2 Agro forestry and restoration purposes

Members of albizias have shown great potential like *A. lebbeck* and *A. procera* have shown high potential in the soil redevelopment process during the early phase of mine spoil restoration in dry tropical environment (Singh *et al*., 2004).

4. History of albizia tree improvement in india

The history of genetic improvement of *Albizia* in India is a relatively recent but growing field of research, with efforts intensifying since the late 20th century.

Early/colonial to mid-20th century: *Albizia* species were introduced, assessed and used widely in agroforestry, pastoral shade and roadside plantings. Early silvicultural and provenance observations were recorded in forestry literature.

Late 20th century (1970s–1990s): National forestry institutions ICFRE and its regional institutes such as TFRI) began organized trials, provenance collections and plantation technique research for *Albizia* spp.; some work targeted reclamation (mine spoil, wastelands) and spacing/fertilizer trials. The formation of ICFRE and, in 1988 reorganization of the Forest Research Institute led to creation of the Division of Genetics and Tree Propagation. The priority of research was to genetically improve yhe namely species *Acacia nilotica, A. catechu, Albizia* spp., *Azadirachta indica, Dalbergia sissoo, Eucalyptus* spp., *Pinus roxburghii, P. wallichiana* and *Tectona grandis*.

2000s–present: still till date there is continuation of ecological and provenance studies, regeneration assessments, site-specific trials and increasing interest in vegetative propagation/tissue culture and seed production areas; but few coordinated, long-term genetic improvement programmes specifically aimed at breeding superior *Albizia* cultivars have been published. Meenakshi *et al*. , 2023, studied intra provenance variation in seed morphological traits and germination in *A. procera* in the mid-Himalayan region. Significant variation among provenances was found. The populations of *Albizia chinensis* distributed in Himachal Pradesh and Uttarakhand (Dhanai *et al*. 2003a Todaria *et al*. 2003) from Garhwal Himalaya and Siwaliks, Uttaranchal, Uttar Pradesh were observed for pod and seed morphology and studied their genetic characters. Seedling characters of *Albizia chinensis* (Osbeck) (Dhanai *et al*. 2003b) and *A. lebbeck* (Bahar, 2008) were studied.

5. Future research thrusts/priorities

1. Survey in Albizia rich area and assessment of biodiversity

2. Provenance and clonal trial (Multilocational test)

3. Collection, screening, selection of genotypes of important species at regional, national and international level.

4. Standardization of vegetative propagation techniques and cryopreservation for elite clones.

5. Study of reproductive biology.

6. Cytological studies.

7. Establishment of seed orchard/germplasm bank for top provenances.

8. Invitro induction of flowering and hybridization.

9. Study of genetic markers in genetic diversity analysis, parentage analysis, and association mapping for traits of interest.

Conclusion

Genetic improvement *of Albizia* species in India, especially *A. lebbeck*, *A. procera*, *A. amara*, is still in infancy. Existing studies in India show that remarkable variation exists in albiizas particularly in good phenotypic variability in growth seed/pod and seed quality traits, high heritability for some key traits, and possibilities for vegetative propagation. But major constraints in improvement are in especially scarce molecular resources, standardized propagation, seed certification, wide geographical evaluation and stakeholder engagement. For the holistic Improvement of commercial and ecological utilization of genus Albizia legumes, coordinated, sustained programme combining conventional breeding, genomics/biotechnology, and strong seed/nursery systems, aligned with policy and stakeholder needs, can deliver improved *Albizia* genotypes that meet both ecological and economic needs in India.

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HIGH-DENSITY APPLE PLANTATIONS IN KASHMIR: PRODUCTIVITY, PRESERVATION, AND THE SCIENCE OF BALANCE

Introduction

Kashmir's apple industry stands at a historic crossroads. The rapid transition from traditional low-density orchards to High-Density Plantation (HDP) systems represents one of the most transformative shifts in the region's horticultural history. Scientifically defined, HDP apple cultivation refers to orchard systems characterized by high planting density (2,000–4,000 trees per hectare), dwarfing rootstocks (M9, M26, MM106), compact tree architecture, early bearing, and intensive canopy and nutrient management. These systems are designed to maximize yield efficiency (kg fruit per cubic meter canopy) rather than tree size.

Undoubtedly, HDP has introduced precision horticulture into Kashmiri orchards. Farmers now cultivate spur-type cultivars such as Gala, Fuji, Red Velox, Super Chief, and Jeromine, grafted onto clonal dwarfing rootstocks that induce precocity, uniformity, and higher harvest indices. The benefits are clear:

- Early economic returns (fruiting within 2–3 years instead of 6–8),
- Three- to four-fold yield enhancement,
- Improved light interception,
- Better pest and disease management, and
- Compatibility with mechanization, fertigation, and protected inputs.

Economically, this transition has strengthened Kashmir's position in national and global apple markets. Yet, beneath this visible success lies a quieter, more fragile loss—one that economics alone cannot quantify.

As Allama Iqbal poignantly asked:
"Jo tujhe nahin mila, usko khoya kaisay samjha jaye?"
That which you never valued—how will you recognize its loss?

Genetic Uniformity vs. Genetic Resilience

From a scientific perspective, HDP systems inherently promote genetic narrowing. The replacement of heterogeneous, seedling-origin, regionally adapted landraces with a small genetic pool of elite cultivars reduces allelic diversity, increasing vulnerability to biotic and abiotic stresses. Traditional Kashmiri apple varieties—Ambri, Maharaji (White Dotted Red), American Trelli, Crab apples, and diverse Delicious strains—may no longer dominate commercial markets, but they represent locally evolved gene complexes shaped by centuries of natural and farmer-led selection under Kashmir's unique temperate agro-ecology. These varieties often exhibit:

- Enhanced tolerance to apple scab, powdery mildew, and frost injury,
- Greater phenological synchronization with local climate patterns,
- Rootstock–scion compatibility evolved in situ, and
- Adaptive plasticity under climatic uncertainty.

As M.S. Swaminathan wisely warned:
"Monocultures may feed the present, but biodiversity sustains the future."
In scientific terms, genetic diversity is an insurance policy—a living repository of resistance genes, stress tolerance traits, and adaptive potential essential for future breeding programs.

Cultural Orchards and the Ecology of Memory

Beyond genetics, apples in Kashmir occupy a socio-cultural and emotional ecology. Traditional orchards were not merely production units; they were intergenerational landscapes—sites of shared labor, folklore, seasonal rituals, and collective identity. Each cultivar carried a sensory signature—a taste, aroma, and harvest rhythm deeply woven into village life.

The wholesale replacement of such orchards with uniform, market-driven plantings risks converting a living heritage into a standardized commodity.

As poet Rahi Masoom Raza observed:
"Apne darakhton ki khushboo ko pehchano,
warna sheheron ki dhool tumhe be-watan kar degi."
Recognize the fragrance of your own trees, or the dust of cities will make you homeless.

This is not an argument against progress, but against amnesia. Cultural erosion often begins where diversity is dismissed as inefficient.

Institutional Responsibility: A Dual Scientific Mandate

Institutions such as ICAR-CITH Srinagar, SKUAST-Kashmir, Krishi Vigyan Kendras, and State Horticulture Departments must therefore adopt a dual research and development mandate:

1. Productivity and Precision Research

- Optimization of HDP-compatible scion–rootstock combinations,
- Development of climate-smart orchard management protocols,
- Precision nutrient and water-use efficiency research, and
- Strengthening farmer profitability and export competitiveness.

2. Conservation and Genetic Security

- Establishment of field gene banks and in situ conservation orchards,
- Cryopreservation and in vitro conservation of elite landraces,
- Molecular characterization and DNA fingerprinting of indigenous cultivars,
- Integration of traditional germplasm into future breeding pipelines.

3. Community-Centered Conservation

- Creation of "Heritage Orchards" or "Cultural Blocks" at village level,
- Cooperative models linking heritage apples with agro-tourism, niche markets, and GI branding,
- Farmer-led participatory conservation aligned with economic incentives.

Diversity as Biological and Philosophical Survival

From the standpoint of plant science, diversity buffers epidemics. Uniform HDP orchards amplify systemic risk; diverse orchards diffuse it. Wild relatives such as *Malus sieversii* and *Malus baccata*, along with traditional Kashmiri cultivars, harbor genes conferring resistance to scab, fire blight, drought stress, and cold injury—traits increasingly vital under climate change.

In scientific language, diversity equals resilience.
In poetic language, diversity equals survival.

As Sir C.V. Raman reminded us:
"The true wealth of a nation lies not in its gold or silver, but in its natural resources and the genius of its people."

Conclusion: Beyond Gain and Loss

The transformation of Kashmir's apple industry need not be framed as a conflict between tradition and technology. The real challenge is integration—to design an orchard future where high-density systems coexist with heritage conservation, where science walks alongside memory, and where productivity does not come at the cost of identity.

As Iqbal envisioned:
"Nayi manzilen, nayi rahguzar — purane chiragh bhi saath le chalo."
Seek new destinations and new paths, but carry your old lamps with you.

Only then can Kashmir's orchards remain globally competitive, ecologically resilient, and culturally rooted—bearing not just fruit, but wisdom.

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5 FLOWERING ANNUALS THAT THRIVE ON NEGLECT FOR A STUNNING GARDEN WITH MINIMAL EFFORT

Introduction

A lot of perennials thrive on neglect if you're on the hunt for flowers that grow back every year, but annual flowers are the one-hit-wonders of the garden, putting out one round of blooms before dying back at the end of the growing season.

Many annual flowers perform well even when they're left to fend for themselves – there are some annuals you don't need to deadhead, for example. If you're short on time or simply want an easy-care garden, here are some of the best flowering annuals that thrive on neglect.

1. Marigold

Marigolds are a superhero plant in any garden: vibrant, easy to grow, and the perfect companion planting idea for attracting natural pest predators like ladybirds. Better yet, they're the perfect example of flowering annuals that thrive on neglect.

'Marigolds are a reliable option because they bloom for months and only need a sunny spot to keep looking their best,' explains Julian Palphramand, head of plants at British Garden Centres.

1. Cosmos

If you're looking for a low-maintenance annual, learn how to grow cosmos – they're one of the toughest flowers out there, and they can tolerate a surprising level of neglect.

'Once established, cosmos can handle drought, poor soil and some general neglect,' says Richard Barker, commercial director at LBS Horticulture. 'They tend not to be bothered by garden plant pests, and although they can be deadheaded, they will self-seed if the flowers are left in place.'

Plant chocolate cosmos from Crocus for rich, velvety blooms.

2. Zinnias

For ultra-vibrant flowering annuals that thrive on neglect, learning how to grow zinnias is the way forward. These colourful blooms will flower even if you skip watering from time to time.

'Zinnias are a great choice because they thrive in full sun and don't mind if you forget to water them occasionally,' says Julian.

Sow *Zinnia elegans* 'Queen Lime Red' from Crocus for unique pale red and lime green blooms, or try *Zinnia elegans* 'Zinderella Peach' from Thompson & Morgan for fluffy flowers.

3. Sunflowers

Whether you learn how to grow sunflowers in pots or garden borders, these classic annuals are both easy and rewarding.

'Sunflowers are almost foolproof, starting easily from seed and growing tall with minimal effort,' says Julian.

Although it's a little late (though not impossible) to plant sunflower seeds now, you can buy sunflower plants for just £1.99 from Gardening Express.

5. Annual salvias

Annual salvia varieties are among the best drought-tolerant plants out there, and a real hit with pollinators.

'Varieties such as salvias are perfect examples of plants that can withstand minimum care but still deliver vibrant blooms, making them ideal for those who are looking to maximise colour in their garden,' say the horticultural experts from Cherry Lane Garden Centres.

'These annuals are known for their resilience, flourishing during dry spells with little watering, and even when planted in poor soil conditions.'

Salvia splendens 'Blaze of Fire' from Thompson & Morgan produces vibrant red blooms.

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FROM DROUGHTS TO DELUGE: HOW MAIZE FARMERS CAN ADAPT TO CLIMATE CHANGE

Introduction

The impacts of climate change are being increasingly felt worldwide, with agriculture being one of the most affected sectors. Maize, a key staple crop and vital source of food and income for millions of farmers, is particularly susceptible to changes in weather patterns, making it highly vulnerable to climate change. Farmers are facing unpredictable weather, such as severe droughts and flooding, which are leading to reduced yields, crop failures, and financial difficulties. Despite these challenges, there is hope. With innovation, technology, and adaptive strategies, maize farmers can find ways to cope with the changing climate and protect their livelihoods.

Maize thrives under specific weather conditions consistent rainfall, moderate temperatures, and abundant sunlight. When climate change disrupts these factors, farmers are faced with serious challenges. Droughts are becoming more frequent and intense, particularly in areas dependent on rain-fed agriculture. A lack of water leads to stunted crops or failed harvests, which directly impacts food security and farmer income. On the other hand, heavy rains and floods are becoming more common in some regions. Flooding can damage maize crops by washing away soil, eroding the land, and delaying planting and harvesting. These extreme weather patterns make it increasingly difficult for farmers to predict what they will face, creating a cycle of uncertainty.

One of the most effective ways to address the impacts of climate change is by using drought-tolerant maize varieties. Scientists have developed hybrid maize seeds that are specifically engineered to endure drought conditions. These varieties are designed to retain moisture and continue growing, even when water is scarce. In areas like sub-Saharan Africa, where droughts are becoming more frequent, these drought-resistant varieties have become a vital solution. Although they aren't a perfect fix, they give farmers a better opportunity to survive dry periods and sustain some level of productivity, even under difficult circumstances.

In addition to using drought-resistant maize, improving water management is another crucial strategy for adapting to climate change. Water is essential for maize growth, and implementing effective water management practices can significantly impact a crop's ability to thrive during dry periods. One of the most promising approaches to addressing water shortages is rainwater harvesting. By collecting and storing rainwater during wetter seasons, farmers can build a reserve of water to use during droughts. This method is especially beneficial in areas with unpredictable rainfall or limited access to irrigation systems.

Another effective water-saving technique is drip irrigation, which provides water directly to the plant roots in small, controlled amounts. This method minimizes water waste and ensures that crops receive the right amount of water, even during droughts. Drip irrigation systems are particularly useful in regions that experience both drought and flooding, as they offer better control over water usage. By reducing the risk of over-watering, farmers can prevent flood damage and ensure their crops get the appropriate moisture needed to grow.

Soil health is another key factor in adapting to climate change. Healthy soil is crucial for supporting crops, especially maize, which has high nutrient needs. As weather patterns become more unpredictable, farmers must adopt practices that protect and improve soil quality. One such practice is no-till farming, where farmers leave the soil undisturbed after harvest instead of plowing it. This method reduces soil erosion, enhances water retention, and helps build organic matter in the soil. Well-maintained, structured soil is more resilient to both droughts and floods, making it a vital element of climate resilience.

Cover cropping is another vital soil management practice. During the off-season, planting cover crops such as legumes helps protect the soil from erosion and enhances its fertility by adding organic matter. These crops also assist in retaining moisture in the soil and provide extra protection during heavy rainfall, preventing the loss of valuable topsoil. By combining cover cropping with no-till farming, farmers can greatly improve soil health and boost their resilience to climate extremes.

Diversification is another crucial strategy for managing the risks posed by climate change. By planting a variety of crops alongside maize, farmers can spread financial risk and lessen the impact of crop failure. If one crop fails due to drought or flooding, other crops may still thrive, offering an alternative source of income and food. In many regions, intercropping—planting multiple crops such as beans, potatoes, or cassava alongside maize—is becoming more common. This practice not only reduces the risk of total crop loss but also enhances soil health by promoting biodiversity and disrupting pest cycles.

Agroforestry is another promising practice gaining traction, which involves incorporating trees into farming systems. Trees can shield crops from extreme weather events by offering shade during heatwaves and reducing soil erosion during heavy rainfall. The roots of trees also contribute to improving soil structure and water retention, keeping the soil fertile and stable. Beyond the environmental benefits, trees can also provide farmers with an additional income source through timber, fruit, or nuts, further diversifying their revenue streams.

Technology is a powerful tool for helping maize farmers adapt to climate change. Advances in weather forecasting, soil sensors, and mobile apps are equipping farmers with the information they need to make more informed decisions. Improved weather forecasts allow farmers to plan planting and harvesting around expected weather patterns. Soil moisture sensors enable real-time monitoring of crop health, helping farmers adjust irrigation schedules and manage water use more efficiently. In some regions, drones are being used to monitor crop health and assess field conditions, giving farmers an aerial perspective of their land and helping them detect issues before they become significant problems.

Governments and agricultural organizations also have a crucial role in supporting farmers through policies and financial incentives. They can provide subsidies for drought-resistant seeds, irrigation systems, and climate-smart technologies. Additionally, investments in infrastructure projects like improved irrigation, roads, and weather monitoring stations can help farmers better manage the challenges of a changing climate. Financial safety nets, such as crop insurance or emergency relief funds, can offer protection when extreme weather events cause crop loss. Governments can also encourage sustainable farming practices through policies focused on soil conservation, water management, and agroforestry.

Farmers are on the frontlines of climate change, and their resilience is essential for ensuring food security in a warming world. Although the challenges are substantial, the solutions are within reach. By embracing new technologies, adopting sustainable farming practices, and diversifying crops, maize farmers can reduce the impacts of both droughts and floods. With innovation, collaboration, and government support, a more resilient and sustainable future for maize farming is possible, allowing this vital crop to continue feeding the world for generations. While the path to adaptation may be challenging, it is one that farmers can navigate with hope, determination, and the right resources.

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ROLE OF MILLETS IN NUTRITIONAL SECURITY AND CLIMATE RESILIENCE

INTRODUCTION:

Millets are a group of small-seeded grasses that play a significant role in ensuring nutritional security and promoting climate resilience, particularly in arid and semi-arid regions . These crops are traditionally cultivated in parts of Africa and Asia, and are notable for their high nutritional value, including dietary fiber, vitamins, minerals, and protein. Specific varieties, such as pearl millet, finger millet, and foxtail millet, offer distinct benefits, including elevated levels of essential micronutrients.

The cultivation of millets is characterized by their remarkable resilience, as they can thrive in less fertile soils and require minimal water, making them an ideal crop for dry areas. This is particularly significant in the context of climate change, which poses a substantial threat to food security through rising temperatures and unpredictable rainfall patterns. Millets offer a sustainable solution, particularly for smallholder farmers with limited land and resources, as they provide a viable yield with minimal care and management.

Crop	Scientific name	Origin	Chromosome number
Sorghum	*Sorghum bicolor*	North Eastern Africa	2n = 2x = 20
Pearl Millet	*Pennisetum glaucum*	West Africa	2n = 2x = 14
Finger Millet	*Eleusine coracana*	East Africa, India	2n = 2x = 36
Foxtail Millet	*Setaria italic*	Eastern Asia	2n = 2x = 18
Proso Millet	*Panicum miliaceum*	Egypt and Arabia	2n = 2x = 36
Barnyard Millet	*Echinochloa frumentacea, E. utilis*	India, Japan	2n = 2x = 54
Little Millet	*Panicum sumatrense*	Southeast Asia	2n = 2x = 36

India is a leading producer of millets, and has recognized the importance of these crops, designating 2018 and 2023 as the National and International Years of Millets, respectively. The country's main millet-producing states, including Rajasthan, Karnataka, and Maharashtra, account for a significant proportion of global production. Given the vulnerability of major staples like wheat, rice, and maize to climate-related shocks, millets are an attractive option for policymakers and farmers seeking climate-resilient agricultural practices.

In this context, millets have the potential to address nutritional insecurity and climate change challenges, making them a vital crop for sustainable agriculture and food security.

Food grain	Protein (g)	Fat (g)	Crude fiber (g)	Minerals		Sulfur containing amino acids		Unsaturated fatty acids		
				Ca(mg)	Fe(mg)	Methionine	Cysteine	Oleic	Linoleic	Linolenic
Finger millet	7.3	1.3	3.6	344	3.9	210	140	-	-	-
Kodo millet	8.3	1.4	9.0	27	0.5	-	-	-	-	-
Proso millet	12.6	1.1	2.2	14	0.8	160	-	53.80	34.90	-
Foxtail millet	12.3	4.3	8.0	31	2.8	180	100	13.0	66.50	-
Little millet	7.7	4.7	7.6	17	9.3	180	90	-	-	-
Barnyard millet	6.2	2.2	9.8	20	5.0	180	110	-	-	-
Sorghum	10.4	1.9	1.6	25	4.1	100	90	31.0	49.0	2.70
Bajra	11.6	5.0	1.2	42	8.0	150	110	25.40	46.0	4.10

Millets are a nutrient-rich group of small-seeded cereals, offering a broad spectrum of essential nutrients. They provide a balanced mix of macronutrients, including complex carbohydrates for sustained energy release, moderate levels of plant-based protein (7-12%), and a high amount of dietary fiber that supports digestive health and satiety. Notably, the protein in millets boasts a better amino acid profile compared to refined grains like polished rice, enhancing their value in a balanced diet.

Millets are a treasure trove of micronutrients, making them a potent tool against hidden hunger . Key highlights include:

- Iron-rich pearl millet (bajra): A vital source of iron, crucial for preventing iron-deficiency anaemia, a widespread health issue in many communities.
- Calcium-packed finger millet (ragi): With calcium levels surpassing those of rice and wheat, finger millet supports bone health, growth, and development—essential for children, teenagers, and expectant mothers.
- - Zinc and Magnesium: These minerals play pivotal roles in immune function, enzyme activity, and metabolic processes, contributing to overall health and resilience.
- - Phosphorus and Potassium: Supportive of energy metabolism, cardiovascular function, and maintaining electrolyte balance, these minerals round out the nutritional benefits of millets.

The low glycaemic index (GI) of millets offers multiple health advantages :

- - Blood Sugar Regulation: Helps manage and prevent spikes in blood glucose levels, beneficial for individuals with diabetes.
- - Weight Management: Promotes satiety and reduces cravings, aiding in weight control efforts.

- Heart Health: Linked to reduced cholesterol levels and lower risks of cardiovascular diseases.

Climate Resilience of Millets: A Key to Sustainable Agriculture:

SOURCE-https://agriculturepost.com/agri-research/icrisat-corteva-joint-research-decodes-pearl-millets-climate-resilience-and-nutritional-secrets/

Millets are a vital crop for ensuring food security and promoting sustainable agriculture, particularly in regions with challenging environmental conditions. Their unique characteristics make them an ideal choice for arid and semi-arid areas, where other crops often struggle to thrive.

One of the primary advantages of millets is their exceptional drought tolerance. This is attributed to their deep root systems, which enable them to access moisture from deeper soil layers, allowing them to survive and produce reliable yields in areas with limited rainfall. Pearl millet and finger millet are notable examples of millet varieties that have demonstrated remarkable drought tolerance.

In addition to their drought tolerance, millets are also adaptable to nutrient-poor soils. They possess efficient nutrient use mechanisms, enabling them to grow and produce yields in soils with limited fertility. This makes them an attractive option for farmers seeking to cultivate crops in areas with challenging soil conditions.

Millets also offer significant environmental benefits. They require substantially less water and nutrients compared to staple crops, making them a more sustainable choice for agriculture. Furthermore, their higher nitrogen use efficiency reduces the need for nitrogenous fertilizers, promoting environmentally sustainable agriculture.

The resilience of millets to pests and diseases is another significant advantage. They possess natural defense mechanisms, minimizing the need for chemical pesticides and promoting more sustainable agricultural practices.

In conclusion, millets are a climate-resilient crop that can play a crucial role in promoting sustainable agriculture and ensuring food security. Their adaptability, water efficiency, and natural resistance to pests and diseases make them an attractive option for farmers and policymakers seeking to promote environmentally sustainable and climate-resilient agricultural practices.

MILLETS AND FOOD SECURITY:

Millets play a crucial role in enhancing food and nutritional security, particularly in regions vulnerable to hunger and malnutrition. Their diverse nutrient profile makes them effective in addressing both calorie deficiency and micronutrient shortages. Regular inclusion of millets in daily diets can help reduce the prevalence of conditions such as anemia and mineral deficiencies, especially among women and children.

The nutrients present in millets are generally well absorbed by the human body, increasing their nutritional effectiveness. Incorporating millets into food systems also promotes dietary diversity, which is a key element of balanced nutrition. In many traditional food cultures across Africa and Asia, millets have long been consumed in various forms, reflecting their versatility and cultural acceptance.

From an economic standpoint, millets are advantageous due to their low input requirements and resilience to climatic stress. These traits reduce cultivation risks and production costs, making them particularly suitable for smallholder farmers. The growing global demand for nutritious and functional foods has further enhanced market opportunities for millet-based products, offering pathways for rural income generation and livelihood improvement.

Government Initiatives and Policy Support for Millets:

Need for shift in focus from food security to nutrition security: PM

Modi addresses experts at first Emerging Science Technology and Innovation Conclave, which replaces the Indian Science Congress

The Hindu Bureau
NEW DELHI

In his inaugural address at the first Emerging Science Technology and Innovation Conclave (ESTIC) here on Monday, Prime Minister Narendra Modi said India's scientists should generate ideas to move from food security to nutrition security; create biofortified crops to address malnutrition; develop low-cost fertilizers; better map India's genomic biodiversity for personalised medicine; and arrive at new and cheap innovation in clean battery storage.

"This conclave should make a collective roadmap towards achieving these goals," Mr. Modi said, addressing an auditorium full of representatives from scientific Ministries, and technologists.

Commencing his speech by congratulating the Indian women's cricket team on their maiden World Cup win, he said the 21st century was an epoch of "unusual changes" that were being shaped by science and technology.

PM Narendra Modi with Union Minister of State Jitendra Singh at the opening of ESTIC in New Delhi on Monday. SUSHIL KUMAR VERMA

Doubling R&D

India's expenditure on research and development had doubled in the past decade, the number of patents registered had grown 17 times, and the number of "deep-tech start-ups" risen to 6,000, Mr. Modi said. India had made operational a fund of ₹1 lakh crore via the Anusandhan National Research Foundation, which would help scientists and technologists in the public and private sectors to invest more substantially in research and development, he said.

The ESTIC replaces the Indian Science Congress, the oldest congregation of scientists in India, with a history predating Independence. Over the years, the Indian Science Congress had gone into oblivion, with its last session held in 2023.

The ESTIC continues till November 5, with sessions on quantum science, bio-engineering and energy environment, and climate.

1. Shree Anna Mission (Millet Mission): Launched as a national initiative, this mission promotes millets as a revered food source, focusing on cultivation, processing, research, branding, and market development. It aims to position millets at the core of nutritional and climate-resilient agriculture.
2. National Food Security Mission – Millets Component: Supports millet cultivation through demonstration plots, quality seeds, and farmer training. The scheme enhances productivity in identified districts, ensuring better yields and income for farmers.
3. Public Distribution System (PDS) Inclusion: Millets incorporated into PDS, making them more affordable and accessible to the masses. This initiative supports broader food and nutritional security goals.
4. Supplementary Nutrition Programs: Millet-based meals are being integrated into Anganwadi, school meals, and the PM POSHAN (Mid-Day Meal) scheme to enhance nutritional outcomes for children and vulnerable populations.
5. Production Linked Incentive Schemes (PLI): The government offers incentives for the production of millet-based ready-to-eat (RTE) and ready-to-cook (RTC) products. This encourages industry participation and value addition, boosting the millet market.
6. Support for Entrepreneurs & MSMEs: Startups and micro food processing enterprises involved in millet value chains receive financial and technical assistance under schemes like PMFME (Prime Minister's Formalisation of Micro Food Processing Enterprises).
7. APEDA's Role in Market Development: The Agricultural and Processed Food Products Export Development Authority (APEDA) supports millet export promotion through branding initiatives, global trade facilitation, and the establishment of export forums. This enhances India's presence in international nutri-cereals markets.
8. International Year of Millets (IYOM) – 2023: India led the United Nations to declare 2023 the International Year of Millets, raising global awareness about millets' role in nutrition, sustainability, and resilience. Various events, trade fairs, and roadshows were organized to highlight millets' potential.
9. State-specific Promotion Plans: Several state governments, such as Uttar Pradesh, are implementing their own millet promotion plans. These include increasing the Minimum Support Price (MSP) for millets, expanding procurement

programs, and ensuring farmer incomes and market support.

10. Research and Development: Government-backed research institutions are working on improving millet varieties, enhancing crop yields, and developing climate-resilient strains . This ensures the long-term sustainability of millet cultivation.
11. Awareness and Capacity Building: Initiatives are underway to raise awareness among farmers, consumers, and stakeholders about the nutritional benefits of millets and best cultivation practices. This promotes wider adoption and support for millet-based agriculture.

CHALLENGES AND LIMITATIONS:

Challenges and Limitations

Despite their potential, millets face several constraints that limit their widespread adoption. Limited availability of high-quality seeds often results in suboptimal yields. Market-related challenges, such as inadequate infrastructure, weak supply chains, and uncertain demand, discourage farmers from investing in millet cultivation.

Climate variability, including extreme temperatures and irregular rainfall, continues to affect productivity and grain quality. Many smallholder farmers lack access to modern technologies, extension services, and financial resources needed to manage these risks effectively. Post-harvest challenges, including labor-intensive processing methods and insufficient storage facilities, also contribute to losses.Shifts in consumer preferences toward refined cereals and limited awareness about the health benefits of millets have further reduced their consumption. Policy and market biases favoring major cereals create additional barriers. Addressing these issues requires coordinated efforts in research, infrastructure development, market support, and awareness generation.

CONCLUSION:

Millets are a crucial crop for addressing sustainable agriculture and global food security challenges, particularly in the face of climate change. Their resilience, low resource requirements, and nutritional richness make them an ideal solution for regions with resource constraints and nutritional deficiencies. To realize their full potential, concerted efforts are needed in research, policy-making, and market development. Integrating millets into agricultural systems and food chains can enhance biodiversity, ecological sustainability, and dietary diversity. Future strategies should focus on improving millet varieties, processing techniques, policy support, and global awareness. Embracing millets is a step towards agricultural resilience and a more sustainable, food-secure future.

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PROMISING ROLE OF AZOLLA FOR GREEN FUTURE AND SUSTAINABLE AGRICULTURE

Azolla is emerging as a multifunctional bioresource with significant potential for sustainable agricultural intensification. Owing to its symbiotic association with Anabaena azollae, it provides an efficient system of biological nitrogen fixation, contributing 30–60 kg N/ha and reducing reliance on synthetic fertilizers. Its rapid biomass accumulation and high nutrient content make it a valuable input for green manuring, soil regeneration, and livestock nutrition. Azolla cultivation enhances soil organic matter, improves water retention, and supports microbial diversity, contributing to long-term soil health. Additionally, its dense mat structure suppresses weeds, reduces water evaporation in paddy fields, and aids carbon sequestration, thereby strengthening climate resilience. Despite constraints related to scalability, perishability, and farmer awareness, targeted research and policy support can accelerate its wider adoption in regenerative and low-input farming systems.

Keywords Azolla; Biological nitrogen fixation; Climate resilience; Green manure; Sustainable agriculture

Introduction

Agriculture, the backbone of global food security, is facing increasing pressure from multiple fronts. Farmers worldwide are contending with rising input costs, degraded soils, and an overreliance on chemical fertilizers and pesticides. According to the Food and Agriculture Organization (FAO, 2022), global fertilizer prices rose by more than 70% between 2021 and 2022, largely due to geopolitical disruptions and energy market volatility. This surge has had a particularly severe impact on smallholder farmers in developing nations, where agriculture remains a primary source of income and sustenance.

Simultaneously, long-term use of synthetic chemicals has led to declining soil fertility, contamination of water resources, and decreased crop resilience (Pretty & Bharucha, 2015). These consequences highlight the urgent need for sustainable and affordable alternatives. While organic and regenerative farming practices offer promise, they are often expensive to scale and demand substantial behavioral change.

One promising solution is Azolla, a small, fast-growing aquatic fern that naturally enriches soil by fixing atmospheric nitrogen through a symbiotic relationship with the cyanobacterium Anabaena azollae (Wagner, 1997). Capable of fixing up to 1.5 kg of nitrogen per hectare per day, Azolla's efficiency is comparable to synthetic fertilizers (Singh et al., 2020). Moreover, its high protein content makes it a valuable feed source for livestock and aquaculture.

Azolla grows rapidly doubling in biomass within 3–5 days under optimal conditions and requires minimal inputs, making it suitable for small-scale, on-farm cultivation using basic water bodies like ponds or tanks (Lumpkin & Plucknett, 1980).

With its ecological benefits, affordability, and ease of cultivation, Azolla offers a viable alternative to conventional inputs. As global agriculture seeks more resilient and sustainable solutions, this tiny fern may play a transformative role in shaping the future of farming.

What is Azolla?

Azolla is a genus of rapidly growing aquatic ferns, including species such as *Azolla pinnata, A. filiculoides, and A. caroliniana*. These small, free-floating plants have finely divided fronds resembling moss, with overlapping dorsal and ventral lobes. Root-like structures extend downward into the water, aiding buoyancy and nutrient uptake.

They commonly thrive in tropical and subtropical freshwater habitats—such as ponds, ditches, wetlands, and flooded rice fields, where water is stagnant or slow-moving, sunlight is abundant, and temperatures range between 20–30°C. A key ecological trait is its symbiotic relationship with the nitrogen-fixing cyanobacterium Anabaena azollae, which lives in cavities in the dorsal leaf lobes. This enables Azolla to flourish in nitrogen-poor conditions while enriching surrounding environments with bioavailable nitrogen (Wagner, 1997).

Nutritionally, it contains 20–30% crude protein (dry weight), along with essential amino acids, vitamins (A, B_{12}), carotenoids, and minerals like calcium and iron. Traditionally used as green manure in Asian rice farming, it is now valued in sustainable agriculture, aquaculture, and permaculture systems.

Benefits of Azolla in Agriculture

Azolla may be small, but its impact on agriculture is enormous. From enriching soils to feeding livestock, this tiny aquatic fern is proving to be a game-changer for low-cost, sustainable farming. Here's how:

- **A Natural Source of Nitrogen:** Azolla's unique ability to fix atmospheric nitrogen comes from its symbiotic relationship with the cyanobacterium Anabaena azollae. This partnership naturally delivers 30–60 kg of nitrogen per hectare, reducing or even eliminating the need for chemical fertilizers. In rice paddies, farmers using

Azolla often see improved soil quality over time. It enhances microbial activity, boosts soil structure, and supports lasting fertility without synthetic inputs. By working in harmony with nature, Azolla helps preserve the delicate balance of soil health and promotes sustainable agriculture.

- **A Powerful Green Manure:** Azolla grows quickly, doubling in mass every 3–5 days, and can yield up to 2 tons of dry matter per hectare within weeks. This fast growth makes it an excellent green manure. When mixed into soil, it adds organic matter and humus, helping retain water and improve nutrient holding. Azolla also enhances compost piles by speeding up decomposition and enriching the compost with nitrogen and minerals. For farmers and gardeners, it's a natural, affordable way to boost soil health and support long-term fertility.
- **Natural Weed and Pest Control:** In flooded rice paddies, Azolla forms a dense green mat over the water, effectively blocking sunlight and suppressing weed germination. This natural coverage reduces competition for nutrients and limits the need for herbicides. Recent studies also suggest that Azolla produces secondary metabolites with potential pest-repellent properties (Cannavò et al., 2025). As a result, farmers in regions like India and Southeast Asia are increasingly adopting Azolla as a natural tool for managing both weeds and pests in sustainable rice systems.

Azolla growing in a rice field as a natural nitrogen source

- **Superfood for Farm Animals:** Azolla isn't just beneficial for soil—it's also a valuable livestock feed. With 20–30% protein (dry weight), essential amino acids, vitamins A and B12, and minerals like calcium and phosphorus, Azolla supports poultry, dairy, pig, and fish health. Farmers report improved egg production and milk yield increases of 0.5–1 litre per cow daily. It also cuts feed costs, boosting farm profitability. As a biofertilizer, soil conditioner, weed

A farmer feeding Azolla to chickens at

Input Type	Nitrogen Contribution (kg/ha)	Cost (₹/ha)	Remarks
Azolla (green manure)	30–60	400 – 800	Grown locally; renewable and reusable
Urea (synthetic)	60	4000 – 6000	Requires purchase every season

Sources: Government of India Fertilizer Price Reports (2024); Lumpkin & Plucknett (1980)

Azolla Production Cost Breakdown (Per kg - India)

Assuming a basic on-farm setup using a 10 m² Azolla bed:

Cost Item	Amount (₹)	Remarks
Polythene sheet (for lining)	150	One-time cost (lasts 6–8 months)
Cow dung (5 kg)	25	Initial nutrient source
Azolla starter culture	100	500 g required for 10 m² bed
Water (100–150 L)	0	Typically sourced from existing irrigation
Maintenance (labor/month)	200	Stirring, harvesting, cleaning
Misc. (lime, micronutrients)	50	Supplements added biweekly

Total Cost (First Cycle): ₹525
Yield per cycle (15–20 days): 5–6 kg dry weight or 40–50 kg fresh Azolla
Cost per kg (fresh Azolla): ₹10–13/kg
Cost per kg (dry Azolla): ₹90–105/kg (after drying, optional)

- ***Subsequent cycles only incur maintenance and minimal supplementation costs, bringing the cost down to ₹2–3/kg fresh weight in long-term use.***

suppressant, and animal feed, Azolla is a versatile, sustainable input for regenerative agriculture (Ghodake et al., 2022).

- **Economic Advantages of Using Azolla:** Azolla provides a cost-effective, eco-friendly substitute for synthetic fertilizers, benefiting India's smallholder and marginal farmers. As an aquatic fern partnered with the cyanobacterium Anabaena azollae, it fixes atmospheric nitrogen—up to 50 kg N/ha per crop—significantly cutting chemical fertilizer needs. Field trials and farmers' experiences in Tamil Nadu report 25–40 % cost savings and 30–40 % yield increases using Azolla as basal or dual-crop with rice. (TNAU). Its cultivation requires minimal infrastructure—on-farm ponds or pits—enhancing soil health while reducing environmental harm from synthetic inputs.

Cost Comparison of Inputs per Hectare (approximate, India)

Azolla cultivation requires minimal inputs: a small 10 sq. m tank or pit lined with plastic, filled with water, cow dung, and starter culture—total setup costs range from ₹200–300. It is ready for harvest in 15–20 days and can be reused indefinitely with basic care. Azolla can reduce fertilizer costs by up to 80% per season and serves as a free, protein-rich feed for livestock and poultry, replacing commercial feeds priced at ₹30–50 per kg. This dual function makes Azolla a valuable, low-cost tool for improving soil fertility and livestock nutrition in low-input farming systems (TNAU).

Environmental and Climate Resilience Aspects

1. **High Carbon Sequestration Potential:** Azolla's rapid growth and high photosynthetic capacity allow it to absorb large amounts of atmospheric carbon dioxide. Its symbiotic relationship with *Anabaena azollae* enhances nitrogen fixation, increasing biomass accumulation and enabling Azolla to act as a natural, efficient carbon sink in agroecosystems.
2. **Reduction in Greenhouse Gas Emissions:** Azolla naturally fixes nitrogen, reducing dependence on synthetic fertilizers that emit nitrous oxide (N_2O), a potent greenhouse gas. This eco-friendly alternative lowers emissions from fertilizer production and application, helping to mitigate climate change while maintaining soil fertility and supporting sustainable agricultural productivity.
3. **Water Conservation:** When grown as a surface cover in paddy fields, Azolla reduces water evaporation by blocking direct sunlight. This natural shading conserves water, lowers irrigation requirements, and enhances resilience to drought conditions—an increasingly critical benefit in regions facing water scarcity due to climate change.
4. **Soil Regeneration:** Decomposed Azolla enriches the soil with organic matter and vital nutrients, improving soil texture, water retention, and microbial diversity. It revitalizes degraded soils, supports sustainable farming practices, and contributes to long-term soil health without the environmental drawbacks of chemical soil amendments.
5. **Biodiversity Enhancement:** Azolla mats create a microhabitat for aquatic organisms, beneficial insects, and soil microbes. This enhances biodiversity and ecological balance in paddy fields. Its presence fosters a resilient agroecosystem by supporting natural pest control, nutrient cycling, and healthy biological interactions in farming landscapes.

Challenges in Adoption of Azolla

1. **Perception Issues:** There is a widespread lack of awareness among farmers regarding the benefits of Azolla. Limited training and extension support result in misconceptions about its use, maintenance, and economic value,

Community Based Azolla cultivation with technical support of KVK Parsauni

Integrated Duck–Azolla Farming System developed at KVK Ranchi

hindering widespread adoption across different farming communities.

2. **Scalability Constraints:** Azolla cultivation is typically suited for aquatic or semi-aquatic environments. Scaling it to upland or non-paddy systems poses significant challenges, as it requires continuous water availability and specific environmental conditions to thrive, limiting its applicability across diverse agroecological zones.
3. **Storage and Transportation Limitations:** Azolla has a short shelf-life and is highly perishable. Its high moisture content makes it bulky and difficult to store or transport over long distances without spoilage, restricting its commercial viability and integration into broader agricultural supply chains.
4. **Policy and Research Gaps:** There is insufficient policy support and limited scientific research on improving Azolla strains, optimizing cultivation methods, and integrating it into existing farming systems. This restricts innovation and farmer-level adoption.

Possible Solutions: Strengthening agricultural extension services, establishing community-based Azolla tanks, and developing localized value chains can enhance adoption. Focused research and policy interventions are essential to promote scalability and long-term sustainability.

Innovations and Future Prospects

Advancements in biotechnology are enabling the development of superior Azolla strains with enhanced growth rates, nutrient profiles, and environmental adaptability. Hybrid species are being explored to improve resilience and biomass yield. Azolla's integration into circular farming systems promotes nutrient recycling and sustainability. Its potential as a base for biofertilizer products offers an eco-friendly alternative to chemical inputs. As a climate-smart and regenerative farming resource, Azolla supports soil health, carbon sequestration, and reduced greenhouse gas emissions. Increasing governmental and academic interest, along with growing research investments, is accelerating innovation and expanding its role in sustainable agricultural systems.

Conclusion

Azolla, with its exceptional carbon sequestration ability, nitrogen fixation, and ecological benefits, stands out as a multifunctional resource for sustainable agriculture. Its integration promises a future of climate-resilient, low-input, and farmer-friendly farming systems. To realize this potential, there is an urgent need for expanded research, supportive policies, and farmer-centric education and training. With the right interventions, Azolla can transition from a simple floating fern to a cornerstone of agricultural innovation—ushering in a new era of eco-efficient, regenerative farming. Embracing Azolla today is an investment in a greener, more resilient tomorrow for both agriculture and the environment.

Key Message

Azolla is a low-cost, fast-growing aquatic fern that serves as an efficient biofertilizer and high-quality livestock feed. Its ability to fix atmospheric nitrogen, enrich soil organic matter, and conserve water makes it a valuable input for sustainable and climate-resilient agriculture. Integrating Azolla into farming systems can significantly reduce fertilizer expenses, improve crop productivity, and enhance overall farm profitability. Wider adoption through farmer training, research support, and simple on-farm cultivation models can help transform Azolla into a reliable resource for smallholder farmers across India.