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SCIENTIFIC BEEKEEPING FOR SUSTAINABLE INCOME GENERATION

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Apiculture, also known as beekeeping, plays a pivotal role in the sustainable development of Beekeeping is increasingly recognized as the fifth crucial component of agriculture due to its vital role in agricultural development. It is also considered the fifth essential input for improving yield and ensuring the quality of production in cross-pollinated agricultural and horticultural crops. Tripura possesses abundant floral resources, diverse vegetation, and highly favourable climatic conditions for honey production. Despite these advantages, the state has not yet realized its full potential as a major honey-producing region of the country. This is primarily due to limited awareness, lack of skilled manpower, inadequate integration of beekeeping with agriculture, and insufficient availability of bee colonies for commercial-scale cultivation.

In Tripura, honey is obtained from both wild and cultivated beehives, with nearly 1,000 beekeepers engaged in beekeeping activities. However, most of these beekeepers operate on a marginal scale, managing only one or two hives. Although beekeeping plays an important role in generating employment opportunities and supporting rural livelihoods, its immense potential still remains largely untapped.

Beekeeping holds significant importance within the farming system because of its ecological, economic, and livelihood benefits. The state of Tripura, comprising eight districts, is well known for its rich biodiversity and diverse agro-climatic conditions, making it highly suitable for apiculture. The integration of beekeeping with agriculture can provide farmers with direct benefits such as honey, beeswax, other hive products, and employment opportunities, while also offering substantial indirect benefits through enhanced crop productivity.

Insect pollination is of immense agricultural importance, as only about 5% of flowers are self-pollinated, while nearly 95% depend on cross-pollination. Of this cross-pollination, approximately 85% is carried out by insects, particularly honeybees. Therefore, for achieving increased crop production and sustainable agriculture, it is essential to explore and promote planned bee pollination. Such an approach would serve as a strategic and sustainable solution, benefiting farmers, strengthening the agricultural ecosystem, conserving biodiversity, and supporting the overall environmental health of the region.

Advantages of Beekeeping

- **Low Initial Investment:** Beekeeping requires relatively low capital investment compared to many other agricultural and allied ventures.
- **Less Time-Consuming:** It requires less time and labour for maintenance and management when compared to several other income-generating activities.
- **Utilization of Uncultivable Land:** Beekeeping can be practiced even on uncultivable or marginal agricultural lands, making productive use of otherwise underutilized areas.
- **No Competition for Resources:** Beekeeping does not compete with other agricultural enterprises for land, water, or other major resources, making it highly compatible with integrated farming systems.
- **Pollination Services:** Honeybees provide essential pollination services that support terrestrial ecosystems, enhance biodiversity, and improve agricultural crop productivity.

Modern Beekeeping

Modern beekeeping has advanced significantly through the integration of technology, scientific innovations, and sustainable management practices. One of the most important developments in modern apiculture is the introduction of wooden beehives with movable frames, which provide a well-structured and efficient environment for honeybee colonies to thrive. Unlike traditional hives, modern beehives are specifically designed to improve hive management, maintain colony health, and enhance honey production.

Traditional beekeeping has been practiced since time immemorial, with colony management techniques passed down through generations using indigenous hive designs, cultural practices, and local knowledge. Although traditional beekeeping possesses cultural significance and certain advantages, it also has several limitations such as low productivity, unhygienic honey extraction, destructive harvesting methods, susceptibility to pests and diseases, and poor shelf-life of honey. The adoption of modern beekeeping methods, equipment, and scientific knowledge can help overcome many of these challenges.

Modern beekeeping offers numerous advantages, including higher honey production, improved pollination services, and the production of various hive products. Some of the major benefits are discussed below:

1. Hive Management

Movable-frame hives make the management and inspection of bee colonies easier and more efficient. They provide greater control over colony activities, improve honey extraction efficiency, and minimize disturbance to bees compared to traditional fixed-comb hives. Modern hive designs also ensure better ventilation and insulation, helping maintain optimal temperature and humidity levels that are essential for brood development and honey storage. In addition, bees can be artificially fed during dearth periods when natural food sources are scarce.

2. Honey Production

Modern hives with movable frames can significantly increase honey production. The hive volume can be adjusted according to colony requirements, and additional supers can be added to enhance honey storage capacity. Furthermore, the separation of pollen and brood combs from honeycombs helps in producing high-quality and cleaner honey.

3. Honey Extraction

Mechanical honey extractors are used in modern beekeeping to extract honey from frames without damaging the combs. The intact combs can then be reused by bees, saving energy and enabling faster honey production in subsequent cycles.

4. Pest and Disease Management

Modern beekeeping promotes the use of integrated pest and disease management practices. A combination of preventive and control measures can be applied effectively to manage pests and diseases, thereby improving colony health and productivity.

Constraints in Beekeeping

The Northeast region boasts immense potential for the advancement of beekeeping, thanks to its abundant natural resources, diverse landscapes, and rich cultural heritage. Despite the numerous opportunities, several challenges must be addressed, including:

1. Inadequate infrastructure for the production of genetically superior queen bees for beekeepers.
2. Limited technical expertise for effective bee colony management and maximizing honey production.
3. Insufficient awareness of the benefits of beekeeping for crop yield improvement through pollination.
4. The need for research and strategies for disease management and control in bee colonies.
5. A lack of financial support from institutional sources.
6. Limited consumer awareness regarding honey and its related products.
7. Poor quality control measures in honey production.
8. Ongoing deforestation.
9. The indiscriminate use of insecticides, pesticides, and weedicides.
10. The impact of global warming and unforeseen climatic changes.

Opportunities

The potential for beekeeping development in Northeast India is vast and offers a range of opportunities, including:

- **Diverse Agro-Climatic Conditions:** The varied agro-climatic conditions of the Northeast Hill Region provide an ideal environment for the growth and development of beekeeping activities.
- **Rural Empowerment:** Beekeeping offers immense self-employment potential for rural communities, tribal populations, small and marginal farmers, and landless labourers, thereby contributing to livelihood generation and economic up-liftment.
- **Honey Production:** Honey, owing to its high nutritional and medicinal value, serves as an important source of cash income for beekeepers.
- **Beeswax Production:** Beeswax, which often commands nearly twice the market value of honey, provides an additional and profitable source of income.
- **Bee Pollination Services:** Providing bee pollination services to farmers is a mutually beneficial activity that enhances agricultural crop production while simultaneously improving honeybee productivity, creating a dual-benefit system.

- **Processing and Value-Added Products:** In addition to honey, various value-added products derived from bee by-products offer further opportunities for entrepreneurship, processing industries, and revenue generation.

Economics of Modern Beekeeping

Based on prevailing local market prices, the economic benefits of modern beekeeping in the Northeast Hill Region have been found to be highly promising. Scientific beekeeping has the potential to emerge as a profitable and lucrative agribusiness venture, particularly for unemployed rural youth in the region. Under optimum weather and favourable floral conditions, an average annual revenue of about ₹2.5–3.0 lakhs can be earned from 100 modern bee hives of *Apis cerana* with the adoption of proper scientific management practices. This highlights the immense potential of beekeeping as a sustainable livelihood opportunity and a contributor to rural economic development.

Conclusion

Beekeeping has evolved significantly over the years, from traditional practices to modern scientific methods. The introduction of modern beehives and scientific management techniques has transformed beekeeping into a more reliable, productive, and sustainable activity. Honeybees play a vital role in pollination, supporting the growth and survival of a wide variety of plants, promoting ecological sustainability, and enhancing both the quantity and quality of agricultural produce. The Northeast Hill Region of India, with its rich floral diversity, favourable climate, and traditional knowledge of beekeeping, holds immense potential for the development of apiculture. By adopting sustainable practices, modern management techniques, and benefiting from government initiatives, beekeeping can emerge as an important source of livelihood and contribute significantly to economic development, ecological balance, and food security.

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DEEP POOL AND ITS ROLE IN FISHERIES CONSERVATION

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Deep pools are crucial for river and stream ecosystems, providing essential refuge for fish and other aquatic life. These deep, complex habitats serve as vital breeding grounds and safe havens during extreme weather events like droughts or floods. Research confirms their importance in supporting fish survival and repopulation of degraded areas. However, these pools are threatened by issues like sedimentation and pollution. Protecting them through strategies like habitat restoration and community-driven conservation is essential for preserving freshwater biodiversity and ensuring sustainable fisheries.

Deep pools are fundamental components of river and stream ecosystems that serve as critical habitats for a wide variety of fish species, particularly during reproductive and early developmental stages. These pools are distinguished by their greater depth compared to the surrounding channels, often formed naturally through geological processes or engineered through habitat restoration efforts. The unique physical and ecological characteristics of deep pools make them essential for maintaining healthy fish populations and ensuring the sustainability of fisheries.

One of the primary reasons deep pools are vital for fisheries conservation is their role as refuges during spawning periods. The depth and structure of these pools provide a stable environment that shields fish eggs, larvae, and juvenile fish from the tumult of fast-flowing water, sediment buildup, and temperature extremes. During spawning, many fish species, including trout, salmon, and char, seek out deep pools because these habitats offer a relatively calm setting where eggs are less likely to be dislodged or flooded by currents. This protective environment increases the survival odds of early life stages, which is crucial for the replenishment of fish populations. Moreover, deep pools serve as critical nurseries that support juvenile fish by providing necessary food resources, shelter from predators, and stable conditions for growth.

Importance of Deep pools

The ecological importance of deep pools extends beyond their role in fish reproduction. These habitats contribute to the overall health of aquatic ecosystems by promoting biodiversity and ecological resilience. Deep pools often feature a variety of substrates and structural elements, including rocks, woody debris, and aquatic plants. These features create complex habitats that support diverse assemblages of invertebrates and other aquatic organisms, forming a rich food web that benefits fish and other aquatic wildlife. The heterogeneity within deep pools fosters biodiversity, enabling different species to coexist and thrive (Taylor *et al*., 2019). This ecological diversity enhances the resilience of the ecosystem, allowing it to recover from disturbances such as droughts, pollution, or habitat degradation.

Deep pools are increasingly recognized as keystone habitats that require targeted protection and management. Human activities such as dam construction, water diversion, channelization, and urban development have significantly altered natural river dynamics, often leading to the loss or degradation of deep pools. When deep pools are obstructed or drained, the reproductive success of many fish species diminishes, leading to declines in population sizes and disrupted aquatic food webs. Recognizing the importance of deep pools has led to conservation initiatives aimed at protecting remaining deep pools and restoring degraded habitats. Restoration techniques involve creating or enhancing deep pools by modifying river channels, installing woody debris, or implementing controlled flow regimes to mimic natural processes (Poulsen *et al*., 2002).

The conservation of deep pools is further supported by their role in fostering connectivity within river systems. As crucial spawning and nursery sites, deep pools help sustain fish populations by facilitating migration and gene flow. Maintaining connectivity between different habitats ensures that fish can access suitable spawning grounds, feeding areas, and juvenile habitats across the river continuum. Disconnected or isolated deep pools can lead to genetic bottlenecks and decreased adaptability of fish populations. Therefore, safeguarding these habitats involves not only protecting individual deep pools but also ensuring the overall ecological connectivity of river networks.

Investment in the protection and restoration of deep pools aligns with broader sustainability goals of fisheries management. Effective strategies include establishing protective zones, implementing best practices for land-use and water management, and integrating local community knowledge into conservation plans. Marine protected areas (MPAs) and river management policies that prioritize the preservation of deep pools have demonstrated success in enhancing fish biomass and biodiversity. These conservation strategies contribute to increased resilience of fish populations against environmental stresses and human pressures, ultimately supporting sustainable fisheries that can meet the needs of local communities while conserving aquatic biodiversity.

Deep Pools in Seasonal Cycles, Droughts, and Flow Variation

Rivers and streams are dynamic: flows increase during rain, flood, monsoon, snowmelt; they contract in dry seasons or droughts. Fish and aquatic communities must cope. Deep pools are especially crucial during drying periods:

Deep Pools as Seasonal Safe Havens: Deep pools offer safe havens for fish during harsh dry seasons, especially when lakes shrink or become too salty for survival. In these stressful times, fish instinctively withdraw into deep pools, which retain water and suitable conditions after the main body of the lake has deteriorated. When the environment eventually improves, these fish then return, helping to restore and repopulate the larger lake system.

Survival Strategies in Intermittent Water Systems: In river systems that do not flow year-round, the existence of lasting, deeper pools is closely linked to the ability of fish populations to survive extended dry spells. Deep pools that maintain their depth are much more likely to preserve aquatic life until rivers or lakes refill, essentially acting as launching points for recolonization as the water returns. In contrast, fish stranded in small, shallow pools that become cut off from the main water body tend to face greater hardship and reduced chances for survival.

Effects of Isolation and Pool Persistence on Fish Populations: The duration for which these pools remain isolated from the main flow is critical. Pools that reconnect quickly with moving water allow fish to recover and migrate more readily, improving their survival. If pools remain cut off for too long, however, fish can suffer from overcrowding, low oxygen levels, and other environmental stresses. Baird 2006 confirm that, in drying rivers, only the deepest and most persistent pools-often those positioned at the lowest points-function effectively as refuges, giving fish the best opportunity to survive through extended dry periods and then recolonize as conditions normalize.

Biological Benefits of Deep Pools

Deep pools do more than just preserve fish in drought. Some of their roles include:

Shelter from Predators and Temperature Extremes: Deep pools serve as life-saving refuges for fish, especially during demanding environmental conditions. The greater depth offers fish protection from dangerous temperature swings, harsh sunlight, and both water and land-based predators. Fish find pockets of cooler water and shaded spots, helping them avoid potentially lethal shallow environments where heat and light levels can become fatal. These pools essentially act as nature's buffers-cushioning aquatic inhabitants against abrupt changes and creating more stable microclimates when the rest of a river or lake becomes inhospitable.

Water Quality and Oxygen Dynamics: Water quality is another vital benefit of deep pools. While poorly connected or stagnant pools can sometimes experience low oxygen, more shaded and properly mingled pools tend to have enough dissolved oxygen for fish to thrive even in dry seasons. The quality of the water in deep pools is a delicate balance; when flows are maintained and shade is available, the risk of oxygen depletion, algal blooms, and buildup of organic debris is reduced. Good management and natural connectivity help sustain the pool's ability to host life over long dry spells.

Nurseries, Breeding Habitat, and Population Recovery: For many fish, deep pools are not only survival shelters but also important nurseries and breeding grounds. Species utilize these deeper zones to lay eggs, nurture fry, and support the early growth of their young-particularly when river flows drop. Both migratory fish and those with specific habitat needs rely on the depth, stability, and food resources available here for successful reproduction and early development. After droughts subside and water returns, deep pools act as biological springboards, allowing surviving fish populations to venture out and replenish wider lake or river habitats, restoring fisheries productivity and ecosystem health.

Threats to Deep Pools and Challenges in Using Them for Conservation

Deep pools are fragile components of freshwater systems. Various threats and ecological traps can limit their benefits:

Connectivity loss: Pools are isolated and flow is decreased via damming, water abstraction, and diversions. Fish cannot move in and out of pools when flow pathways are obstructed or nonexistent, turning pools into dead ends. Under anticipated climate change, the quantity and effective reach of refugia will decrease due to reductions in hydrologic connection, raising the danger of extinction.

Sedimentation and siltation: Silt deposits from upstream erosion can fill up pools, decreasing their depth, volume, and structural complexity. Because of eroded soil and diverting water for agriculture, deep pools within the rivers are becoming silted up, decreasing their capacity to serve as refuges during stressed or dry times.

Water quality degradation: Unsuitable or even fatal deep pools can be caused by pollutants, nutrients, temperature spikes, and oxygen shortages. Changes in fish habitat composition were associated with increasing hypoxia and decreased inundation during the summer.

Over-exploitation: Fishermen frequently target deep pools because they concentrate fish during dry seasons. In a deep pool downstream, fishes seek large fish with hook-and-line fishing and attractants. If not controlled or timed properly, such intense pressure might lead to population declines.

Climate change: In many areas, droughts are expected to increase in frequency and severity. Variations in temperature, precipitation, and evaporation will cause refugia to become more isolated and decrease flows. Many species may lose the ability to access or continue using deep pools if hydrologic connection decreases. Climate change-related declines in connectivity have an effect on dryland stream fishes, particularly on species with restricted mobility.

Conservation Strategies: How to Protect Deep Pools for Fisheries

Mapping, monitoring, and classification: Determine the locations of deep pools, evaluate if they are seasonal, semi-permanent, or permanent, and quantify their volume, depth, network connection, and water quality. To map deep pools in drought-prone environments and evaluate deep pool refugia along major rivers, Sentinel-2 satellite imagery and ground-truthing are typically used (De Meestar *et al*., 2005).

Maintain or restore connectivity: To maintain fish access to pools, it's important to ensure that shallow flow paths are preserved or that there's consistent water flow, especially during dry periods. You should also avoid building structures that isolate these pools. If construction is necessary, make sure to design it in a way that allows fish to move freely between them. Preventing streams from becoming overly fragmented is crucial, as the loss of connectivity significantly increases the risk of local extinctions.

Protect catchment health to prevent sedimentation: By reducing soil erosion upstream through riparian buffers, vegetation cover, and land use policies, pool depth and structure can be preserved.

Regulate fishing in and around deep pools, especially during dry season: Control fishing near and in deep pools, particularly in the dry season. Fish especially at risk at low flow because they cluster in pools. Controlling equipment, time, and attractant use is advantageous. For instance, it is usual practice to utilize bait and huge hooks for large fish; this practice needs to be controlled to prevent overharvesting of populations of larger, slower-reproducing species.

Manage water quality and shading: Maintain riparian vegetation to prevent temperature spikes and shade pools; control nutrient inputs to prevent eutrophication; and, when practical, use flow or aeration to maintain basic oxygen levels. It has been demonstrated that fish communities in backwaters are structured by low dissolved oxygen.

Incorporate deep pools in reserve design and community sanctuaries. Areas designated for conservation (fish sanctuaries, protected reaches) should include deep pools, especially near downstream ends, to serve as refugia for displaced fish. Manna *et al*. 2003 highlighted the freshwater protected areas (FPAs), sites with deep pools often provide lower energy refuges and are critical during displacement events.

Adaptive management under climate change. Monitoring trends in flow, pool persistence, connectivity; anticipating changes; perhaps creating artificial refuges where natural ones are degraded; considering assisted recolonization in some cases.

Conclusion

Deep pools are indispensable habitats that support the reproductive success, growth, and survival of many fish species. Their role in fisheries conservation is multifaceted, encompassing safeguarding fish populations, maintaining ecological integrity, and enhancing the resilience of aquatic ecosystems. Protecting and restoring deep pools requires collaborative efforts among scientists, policymakers, local communities, and stakeholders. Recognizing their ecological and economic importance is key to developing sustainable management practices that ensure the long-term health and productivity of freshwater and coastal fisheries. As pressures on aquatic habitats continue to grow due to climate change and human development, the conservation of deep pools remains a vital element in the global effort to sustain healthy fish populations and resilient ecosystems for future generations.

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LONG-TERM FATE OF NITROGEN FERTILIZERS IN AGRICULTURAL SOILS: IMPLICATIONS FOR SOIL HEALTH AND ENVIRONMENTAL SUSTAINABILITY

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Nitrogen fertilizers play a crucial role in enhancing agricultural productivity and supporting global food security. However, long-term and excessive application of nitrogen fertilizers can negatively affect soil health, water quality, and environmental sustainability. In agricultural soils, nitrogen undergoes several transformation processes including mineralization, ammonification, nitrification, immobilization, denitrification, and volatilization, which influence its availability to plant and its potential losses from the soil system. A major portion of applied nitrogen is utilized by crops, while the remaining fraction may accumulate in soil organic matter or lost through nitrate leaching, surface runoff, and gaseous emissions. These losses contribute to groundwater contamination, eutrophication of aquatic ecosystems, soil acidification, nutrient imbalance, and greenhouse gas emissions. Sustainable nitrogen management practices such as balanced fertilization, precision agriculture, conservation tillage, cover cropping and controlled-release fertilizers can improve nitrogen use efficiency and reduce environmental impacts. Understanding the long-term fate of nitrogen fertilizers is therefore essential for sustainable agricultural production and environmental protection.

Nitrogen fertilizers are indispensable for modern agriculture because they significantly increase crop productivity and support global food security. Rapid population growth and increasing food demand have intensified the use of synthetic nitrogen fertilizers across agricultural systems worldwide. However, continuous and excessive application of nitrogen fertilizers has created serious concerns regarding soil health, environmental sustainability, and water quality (Vitousek *et al*., 1997). Nitrogen added to agricultural soils undergoes several biological and chemical transformations that determine its availability to plants and its eventual fate in the environment.

In agricultural soils, nitrogen exists in multiple forms and continuously cycles through the atmosphere, plants, microorganisms, and soil organic matter. While a major proportion of applied nitrogen is absorbed by crops, a considerable fraction remains in the soil or is lost through volatilization, denitrification, runoff, and leaching. These losses reduce nitrogen use efficiency and contribute to environmental pollution (Giordano *et al*., 2021). Long-term fertilizer use also influences soil pH, nutrient balance, microbial activity, and soil organic carbon dynamics.

Studies conducted at long-term experimental sites have shown that a significant portion of applied fertilizer nitrogen becomes incorporated into soil organic matter and may remain in the soil for several years. Over time, this residual nitrogen can be gradually released through mineralization and may contribute either to crop nutrition or environmental contamination (Sebilo *et al*., 2013). Therefore, understanding the fate of nitrogen fertilizers in agricultural soils is essential for developing sustainable nutrient management practices that optimize productivity while minimizing ecological risks.

Nitrogen Transformation Processes in Soil

Nitrogen in agricultural soils undergoes continuous transformation through microbial and biochemical processes. These transformations determine the availability of nitrogen to crops as well as the potential losses from soil systems.

Mineralization is the process through which organic nitrogen compounds are converted into inorganic forms. During this process, soil microorganisms decompose proteins, amino acids, nucleic acids, and other organic materials to release ammonium. This transformation is essential for maintaining soil fertility because it converts unavailable organic nitrogen into plant-available forms (Jenkinson and Parry, 1989).

Ammonification is a major component of mineralization in which organic nitrogen compounds are converted into ammonium ions. The released ammonium may either be absorbed by plants or undergo nitrification. Nitrification is a microbial process in which ammonium is oxidized first to nitrite and then to nitrate by nitrifying bacteria. Although nitrate is readily available for crop uptake, it is highly mobile and susceptible to leaching losses.

Immobilization is the reverse process of mineralization. During immobilization, soil microorganisms absorb inorganic nitrogen from the soil solution and convert it into microbial biomass. This temporarily reduces nitrogen availability to crops. Balance between mineralization and immobilization depends largely on the carbon-to-nitrogen ratio of soil organic matter.

Denitrification is another important nitrogen transformation process that occurs under anaerobic or waterlogged soil conditions. In this process, nitrate is reduced to gaseous forms such as nitric oxide, nitrous oxide, and nitrogen gas. Denitrification contributes significantly to nitrogen loss from agricultural systems and is also a major source of nitrous oxide emissions.

Volatilization refers to the loss of ammonia gas from surface-applied nitrogen fertilizers, especially urea and ammonium-based fertilizers. This process is influenced by soil pH, temperature, moisture, and wind conditions. Ammonia volatilization reduces fertilizer efficiency and contributes to atmospheric pollution.

Fate of Nitrogen Fertilizers in Agricultural Soil

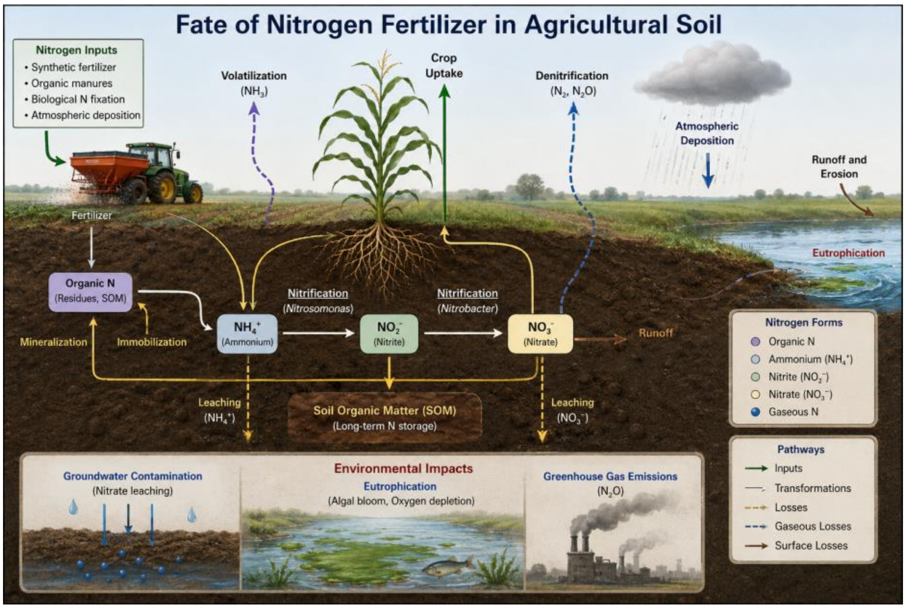
The fate of nitrogen fertilizer in agricultural soil depends on soil properties, climate, crop demand, and management practices. Once applied, nitrogen fertilizers may be absorbed by plants, retained in soil organic matter, transformed into gaseous forms or lost through leaching and runoff.

Research using isotopically labelled nitrogen fertilizers has demonstrated that approximately 40–60 percent of applied nitrogen is taken up by crops during the growing season. A substantial proportion of the remaining fertilizer nitrogen becomes incorporated into soil organic matter and microbial biomass (Sebilo *et al*., 2013). This residual nitrogen can persist in soil for many years and may gradually become available through mineralization.

Nitrate is highly soluble and easily transported through the soil profile with percolating water. Under conditions of heavy rainfall or excessive irrigation, nitrate leaching can contaminate groundwater resources. Elevated nitrate concentrations in drinking water are associated with human health problems and ecological degradation (Ju *et al*., 2006).

Nitrogen may also be lost through surface runoff, particularly in poorly managed agricultural fields. Runoff carrying nitrate and ammonium contributes to eutrophication of rivers, lakes, and coastal ecosystems. Excessive nutrient loading stimulates algal blooms and reduces dissolved oxygen levels, creating aquatic dead zones (Zhao *et al*., 2012).

Long-term fertilizer application can also lead to the accumulation of residual nitrogen in soil. While this residual nitrogen may support crop growth in subsequent seasons, it also increases the risk of environmental losses. The long-term legacy of fertilizer nitrogen therefore remains an important concern in intensive agricultural systems.



Long-Term Effects of Nitrogen Fertilizer Application

Continuous nitrogen fertilizer application has profound effects on soil health, soil fertility, and environmental quality. One of the most important consequences is soil acidification. Ammonium-based fertilizers release hydrogen ions during nitrification, gradually lowering soil pH. Acidification reduces the availability of essential nutrients such as calcium, magnesium, and phosphorus while increasing the solubility of toxic elements like aluminum and manganese.

Long-term nitrogen application can also create nutrient imbalances within the soil. Excessive nitrogen availability may suppress the uptake of potassium, phosphorus, and micronutrients, resulting in nutrient deficiencies and reduced crop quality. Such imbalances often affect plant growth, root development, and resistance to pests and diseases.

Another important consequence is the decline in soil organic matter. High nitrogen inputs stimulate microbial activity and accelerate decomposition of organic materials. Although this may temporarily increase nutrient release, continuous decomposition eventually reduces soil organic carbon content. Declining organic matter negatively affects soil aggregation, water retention, aeration, and overall soil structure (Giordano *et al*., 2021).

Nitrogen fertilizers also influence soil microbial communities. Long-term application may alter the diversity and activity of beneficial microorganisms involved in nutrient cycling and soil health maintenance. Reduced microbial diversity can weaken soil resilience and ecological stability (Dietz *et al*., 2013).

In addition, excessive nitrogen application increases the risk of greenhouse gas emissions. Nitrous oxide produced during nitrification and denitrification is a potent greenhouse gas with a global warming potential much higher than carbon dioxide. Agriculture is therefore considered a major contributor to atmospheric nitrous oxide emissions.

Environmental Implications

The environmental consequences of long-term nitrogen fertilizer use have become a major global concern. Nitrate contamination of groundwater and surface water is one of the most serious issues associated with intensive agriculture. Increased nitrate concentrations in water bodies have been linked to eutrophication, harmful algal blooms, and deterioration of aquatic ecosystems (Ju *et al*., 2006).

Nitrogen losses also contribute to atmospheric pollution. Ammonia volatilization affects air quality and may contribute to acid rain formation. Similarly, nitrous oxide emissions from agricultural soils contribute significantly to global climate change and ozone layer depletion.

Excessive nitrogen use further increases the risk of soil degradation and erosion. Continuous fertilizer application without balanced nutrient management may weaken soil structure and reduce the capacity of soils to retain water and nutrients. These changes ultimately reduce long-term agricultural productivity.

Several studies have emphasized that increasing anthropogenic nitrogen inputs have significantly altered the natural nitrogen cycle in terrestrial and aquatic ecosystems (Vitousek *et al*., 1997). The widespread use of synthetic fertilizers, combined with land-use changes and intensive cropping systems, has accelerated nitrogen losses to the environment.

Mitigation Strategies and Sustainable Nitrogen Management

Improving nitrogen use efficiency is essential for achieving sustainable agricultural production. Several management strategies can help reduce nitrogen losses and enhance fertilizer efficiency. Balanced fertilization based on soil testing is one of the most effective approaches. Applying fertilizers according to crop demand prevents excessive nitrogen accumulation in soil. The adoption of the 4R nutrient stewardship principles—right source, right rate, right time, and right placement—can significantly improve nitrogen management (Ladha *et al*., 2005).

Precision agriculture technologies also offer new opportunities for efficient fertilizer application. Variable-rate application systems, chlorophyll meters, and sensor-based nutrient management tools help farmers apply fertilizers more accurately according to field variability and crop requirements.The use of slow-release fertilizers, controlled-release fertilizers, and nitrification inhibitors can reduce nitrogen losses through volatilization and leaching. Biological nitrification inhibition has also gained importance for improving nitrogen retention and minimizing environmental contamination (Dietz *et al*., 2013).

Conservation tillage, crop rotation, and cover cropping are important sustainable practices that improve soil organic matter and nitrogen retention. Cover crops absorb residual soil nitrogen during fallow periods and release it gradually after decomposition. Reduced tillage also helps maintain soil structure and minimize erosion.

Proper irrigation management is another key factor in reducing nitrate leaching and denitrification losses. Excessive irrigation creates anaerobic conditions that promote denitrification and increase nitrogen movement below the root zone. Efficient irrigation scheduling can therefore improve both water and nitrogen use efficiency.

Conclusion

The fate of long-term nitrogen fertilizer in agricultural soils is controlled by a complex interaction of biological, chemical, and environmental processes. Nitrogen fertilizers are essential for sustaining crop productivity and ensuring food security, yet their excessive and unbalanced use can negatively affect soil health, water quality, and the atmosphere.

A substantial proportion of fertilizer nitrogen is lost through leaching, volatilization, denitrification, and runoff, reducing fertilizer efficiency and increasing environmental pollution. Long-term nitrogen application can lead to soil acidification, nutrient imbalance, decline in soil organic matter, and greenhouse gas emissions.

Adopting sustainable nitrogen management practices is essential for maintaining soil fertility and minimizing environmental risks. Precision agriculture, balanced fertilization, cover cropping, conservation tillage, and improved irrigation management can significantly enhance nitrogen use efficiency. Continued research and monitoring are necessary to better understand the long-term behavior of fertilizer nitrogen and to develop environmentally responsible nutrient management strategies for future agricultural systems.

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NANOBUBBLE TECHNOLOGY: AN EMERGING INNOVATION FOR SUSTAINABLE SHRIMP AQUACULTURE

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The use of shrimp aquaculture has increased rapidly across the world and contributes a large portion of the global food supply of seafood. However, shrimp production tends to have very significant challenges such as poor water conditions, diseases, inefficient aeration and the negative impact of aquaculture on the environment. New technologies—including the use of nanobubble technology—can help solve these issues within shrimp aquaculture through their ability to improve water quality, oxygen transfer and microbial activity in aquaculture ponds. The positive characteristics of nanobubbles (that are generally 200 nanometers or less in size) are due in large part to their unique physicochemical properties of high stability, large surface area and strong oxidative potential,which can have a positive impact on shrimp development, immune system status and pond ecosystem stability while also decreasing pathogenic microorganisms. Research has shown that these benefits will also translate into significant economic and environmental advantages for the sustainable growth of shrimp aquaculture. In conclusion, this article highlights the principles, mechanisms, applications, advantages, and constraints of nanobubble technology used in shrimp aquaculture and outlines the transformative impact of nanobubble technology on the productivity and sustainability of modern aquaculture systems.

Aquaculture plays an important role in global food production as seafood demand increases and natural fish stocks decline. Shrimp aquaculture, particularly the culture of Litopenaeus vannamei, is a major sector contributing to the economies of many countries. However, intensive shrimp farming faces challenges such as poor water quality, oxygen depletion, disease outbreaks, and organic waste accumulation in ponds. Conventional aeration systems, including paddlewheel aerators and diffused air systems, are widely used to supply oxygen, but they often have low oxygen transfer efficiency, creating stressful conditions for shrimp.

Recent advances in nanotechnology have introduced nanobubble technology as an effective solution in aquaculture. Nanobubbles are ultra-fine gas bubbles with high stability and unique physical properties compared to conventional bubbles. They improve oxygen transfer, stimulate beneficial microorganisms, and help control disease-causing pathogens in aquatic systems. Studies have shown that nanobubble technology can enhance shrimp growth, improve pond water quality, and increase disease resistance, making it a promising approach for sustainable aquaculture.

Principles and Characteristics of Nanobubbles

Nanobubbles are tiny gas bubbles in the water with diameters that are generally smaller than 200 nanometers in diameter. Unlike other types of bubbles, which rise to the surface of the water and burst after some time, nanobubbles are highly stable and can float in the water for long periods of time. One of the most unique characteristics of nanobubbles is their large surface area to volume ratio. This enables them to dissolve more gases in water compared to other types of bubbles. Oxygen nanobubbles are thus highly effective in increasing the concentration of dissolved oxygen in water. Another unique feature of nanobubbles is their negative surface charge, also known as zeta potential. This enables them to repel each other and hence do not coagulate easily in water. Another unique feature of nanobubbles is their highly oxidative properties, which are released when the nanobubbles burst and release hydroxyl radicals, which have highly potent antimicrobial properties and can destroy harmful microbes in the aqua environment.

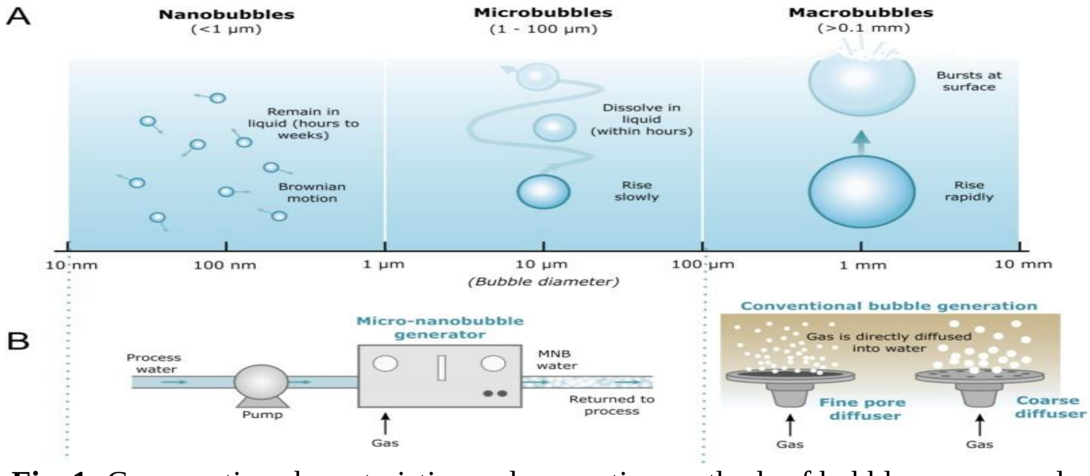

Fig. 1: Comparative characteristics and generation methods of bubbles across scales.

Mechanisms of Nanobubble Technology in Aquaculture

Nanobubble technology affects aquaculture systems in different ways, either biologically, chemically, or physically. One of the ways in which nanobubble technology affects aquaculture is by improving the efficiency of the transfer of oxygen in water. The small size and stability of nanobubbles mean that they dissolve in water over time, allowing the slow release of oxygen into the water column, which is essential for the metabolism and growth of aquatic life (Khan et al., 2022). Another way in which nanobubble technology affects aquaculture is by improving the growth of beneficial microorganisms in aquaculture ponds. The improved level of oxygen in aquaculture systems, which is brought about by nanobubble technology, improves the growth of aerobic microorganisms that help in the breakdown of organic matter and the conversion of toxic nitrogen compounds such as ammonia into harmless compounds. Additionally, there is enhanced sediment oxygenation with reduced production of toxic gases such as hydrogen sulfide. With increased oxygen levels in the pond bed, there is enhanced activity of beneficial microorganisms that degrade organic materials (Zhou et al., 2022). Another significant action of nanobubbles is in controlling pathogens. The oxidative properties of nanobubbles have been known to disrupt microbial cell membranes, thereby controlling the development of harmful bacteria and viruses that cause diseases in aquaculture (Garcia-Segura et al., 2023).

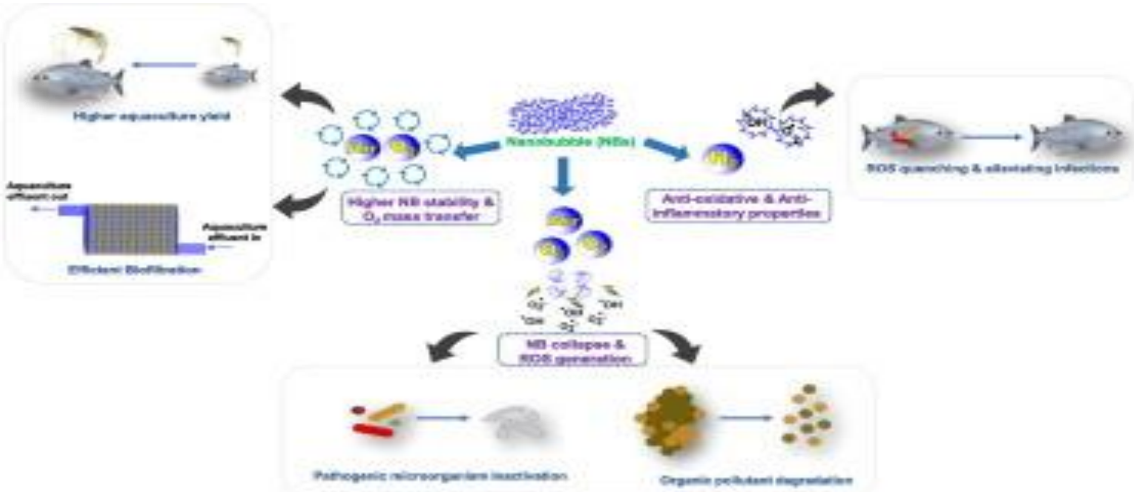

Fig. 1a: Physicochemical properties and biological mechanisms of nanobubbles in aquaculture systems

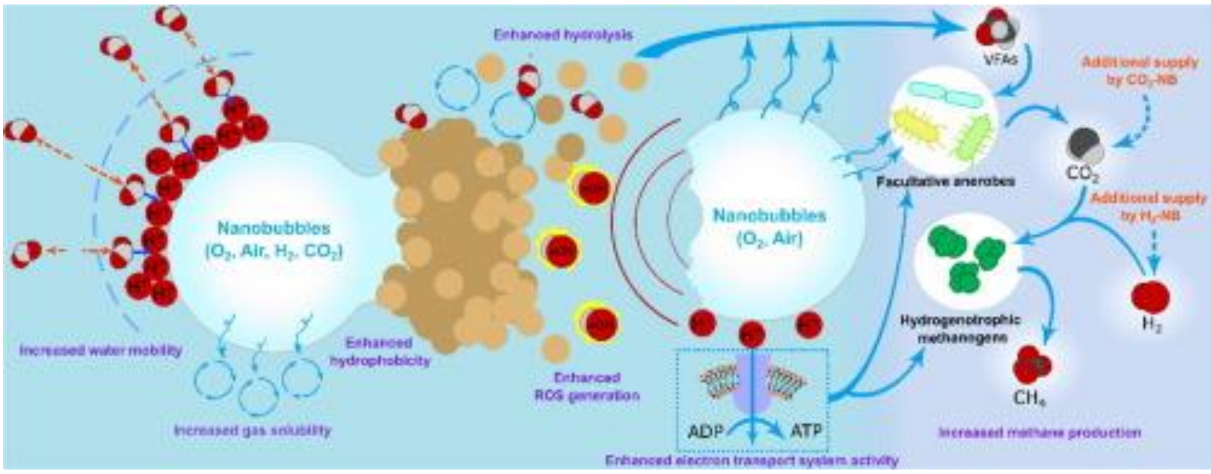

Fig. 2b: Mechanisms of nanobubbles in enhancing microbial activity and methane production.

Role of Nanobubble Technology in Shrimp Aquaculture

Nanobubble technology involves the use of ultra-fine gas bubbles (<200 nm) that remain suspended in water for long periods, supporting physical, chemical, and biological processes in aquaculture systems. In shrimp farming, nanobubbles help maintain dissolved oxygen, reduce organic waste, improve disease control, and enhance overall productivity. Intensive shrimp culture systems often face challenges such as oxygen depletion, waste accumulation, and pathogen outbreaks. Nanobubbles, generated from compressed air or oxygen, provide continuous aeration and improve water quality in systems culturing Pacific white shrimp Litopenaeus vannamei (Temesgen et al., 2021; Khan et al., 2022). One major benefit of nanobubble technology is improved dissolved oxygen availability. Unlike conventional aeration, where larger bubbles quickly escape to the atmosphere, nanobubbles dissolve slowly and distribute oxygen uniformly throughout the pond. This helps maintain adequate oxygen levels required for shrimp respiration, metabolism, and energy production, thereby reducing stress conditions (Choi et al., 2021).

Nanobubbles also improve water quality by enhancing oxygenation in water and sediments. Intensive shrimp farming produces large amounts of organic waste such as uneaten feed, feces, and microbial residues, which can generate toxic compounds including ammonia, nitrite, and hydrogen sulfide. Nanobubble systems stimulate beneficial microorganisms that decompose organic matter and convert harmful compounds into less toxic forms, improving nutrient cycling and pond balance (Wang et al., 2023). In addition, nanobubbles positively influence microbial communities in pond water, sediments, and shrimp intestines. Beneficial microorganisms support digestion, nutrient metabolism, and immune responses in shrimp.

Studies indicate that nano-aeration systems increase beneficial bacterial populations, improve gut microbiota balance, and enhance nutrient utilization and disease resistance in shrimp (Xu et al., 2022).

Nanobubble technology is also effective in pathogen control, particularly when combined with ozone. Ozone nanobubbles generate reactive oxygen species such as hydroxyl radicals that damage microbial cell membranes and suppress pathogen growth. This reduces the risk of bacterial diseases and economic losses in shrimp aquaculture (Liu et al., 2021; Garcia-Segura et al., 2023).The use of ozone nanobubbles has been reported to improve growth performance, feed conversion efficiency, survival rate, and gut microbial balance in Litopenaeus vannamei culture systems by improving water quality and reducing microbial contamination (Phan et al., 2024).Furthermore, oxygen nanobubble systems contribute to ecosystem stability in shrimp ponds by maintaining dissolved oxygen, promoting microbial activity, and reducing harmful metabolites. These effects support sustainable shrimp farming and long-term aquaculture productivity (Zhang et al., 2024).Overall, nanobubble technology offers several advantages in shrimp aquaculture, including enhanced oxygen transfer, improved water quality, beneficial microbial development, pathogen reduction, and better shrimp growth performance, making it an important tool for sustainable aquaculture production (Yaparatne et al., 2024; Sravani et al., 2024).

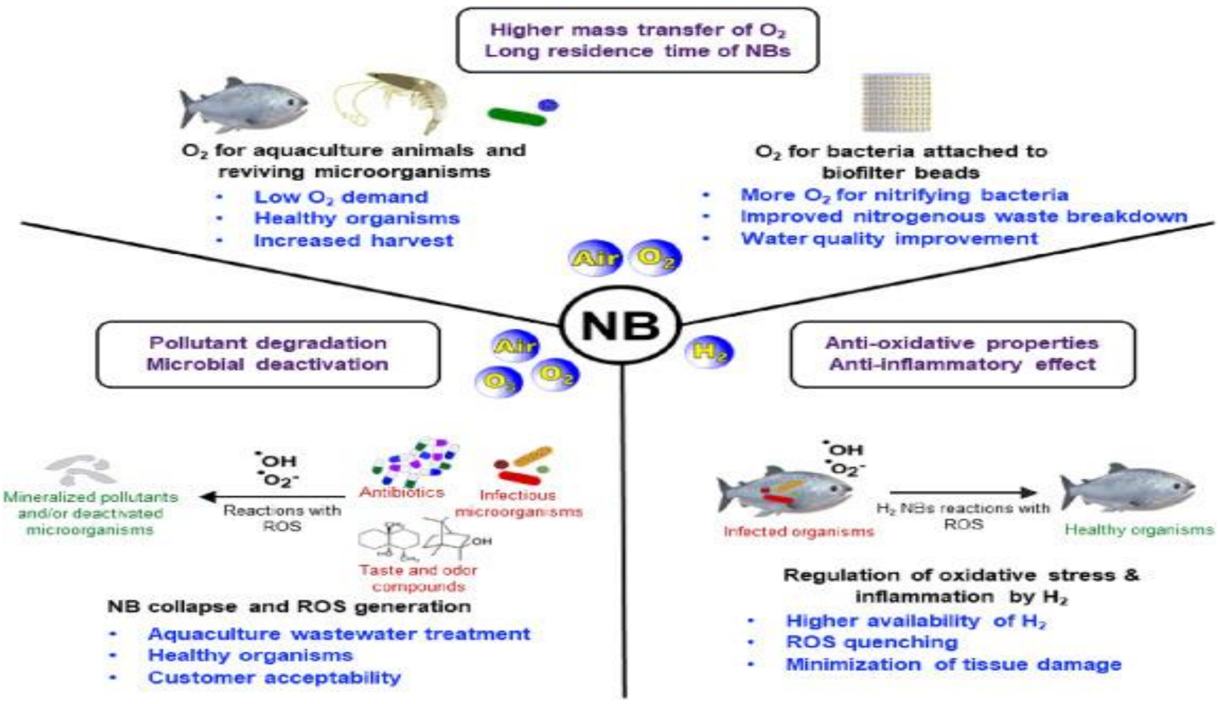

Fig. 3: Functional roles of nanobubbles in shrimp aquaculture systems.

Applications in Shrimp Aquaculture

In shrimp aquaculture, nanobubble technology has numerous real-world uses. The first is the use of oxygen nanobubble aeration to enhance dissolved oxygen levels and support shrimp growth and immunities in culture ponds https://doi.org/10.1016/j.aquaculture.2024.738715 (Zhang et al., 2024). Another application is using ozone nanobubbles for disinfecting water and controlling pathogen populations. Due to the high antimicrobial effect of ozone nanobubbles, they can substantially decrease bacterial numbers in shrimp farms (Phan et al., 2024). Nanobubbles can also be utilized in biofloc systems. Biofloc systems utilize microbial communities to recycle nutrients and transform organic waste into microbial biomass, which the shrimp can eat. The addition of nanobubble aeration increases microbial activity and nutrient recycling efficiency in biofloc systems (Liang et al., 2025). Nanobubbles have alsobeen utilized in aquaculture systems to treat wastewater, which enhances water reuse and minimizes environmental contamination (Yaparatne et al., 2024).

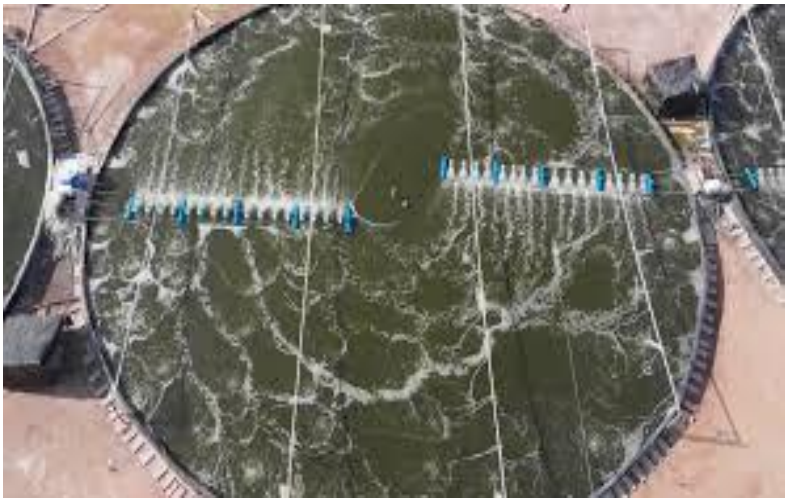

Fig. 4: Field-scale application of nanobubble aeration in shrimp aquaculture ponds.

Advantages of Nanobubble Technology in Shrimp Farming

Nanobubble technology provides several benefits for shrimp farming. The first major advantage is that it provides improved efficiency in oxygen transfer, which is much higher than that of traditional aerators (Khan et al., 2022). This is due to the fact that it enhances aerobic microbial action, which in turn hastens the rate of decomposition of organic waste materials in ponds (Zhou et al., 2022). Another major advantage is that it provides antimicrobial action that is capable of controlling disease-causing organisms in shrimp farming (Garcia-Segura et al., 2023). Moreover, nanobubble technology provides improved growth performance in shrimp, which in turn translates into increased production yields for shrimp farmers (Zhang et al., 2024).

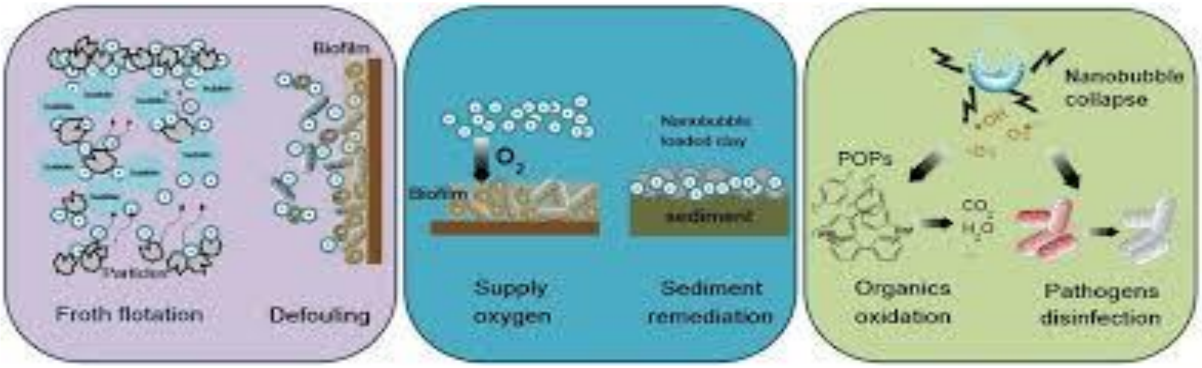

Fig. 5: Environmental and biological applications of nanobubbles in aquaculture systems.

Economic Benefits of Nanobubble Technology

The adoption of nanobubble technology can bring about economic benefits to shrimp farmers. For instance, the increase in oxygen transfer efficiency can reduce the amount of energy used in the aeration system, which can lower the cost of operations in aquaculture farms (Mauladani et al., 2020). Also, the increase in growth performance of shrimp can bring about higher harvest returns to shrimp farmers (Choi et al., 2021). Studies on the economic feasibility of using nanobubble technology in shrimp farming have shown that, although there are investment costs in using the nanobubble system, the long-term benefits of using the system can make it economically feasible for shrimp farming (Mauladani et al., 2020).

Environmental Sustainability

Aquaculture is also benefitting from enhanced environmental sustainability through the use of nanobubble technology. It does this by increasing the oxygen levels in water and also stimulating microbial activity, both of which can help to minimize organic waste build-up and nutrient pollution in shrimp ponds (Wang and collaborators, 2023).

The use of nanobubbles enhances the rate of microbial breakdown of organic materials in water, which will help to lower the amount of harmful gases released into the water, like ammonia and/or hydrogen sulfide, that can adversely affect aquatic-based ecosystems (Zhou and collaborators, 2022).Finally, the use of nanobubbles will also improve the overall wastewater treatment capabilities (efficiency) for aquaculture companies, which will help minimize their environmental impacts and also promote more responsible, sustainable water management (Yaparatne 2024).

Challenges and Limitations of Nanobubble Technology

One major limitation is the relatively high initial cost associated with nanobubble generation equipment compared to conventional aeration systems (Mauladani et al., 2020). Another obstacle is the absence of standard operating procedures for aquaculture applications using nanobubble systems. Recommendations for optimal operating conditions, including bubble size, gas type, and aeration time, are likely to differ based on aquaculture production conditions (Sravani et al., 2024). Finally, more large-scale field studies are required to further assess the effectiveness and long-term environmental consequences of applying nanobubble technology in commercial aquaculture settings (Garcia-Segura et al., 2023). However, ongoing advancements in technology as well as research into enhancing the cost and/or performance of nanobubble systems will facilitate their use over time.

Conclusion

Nanobubble technology is an innovative tool with vast potential to increase the productivity, efficiency, and sustainability of modern shrimp aquaculture systems. Moreover, nanobubble technology is equipped with strong antimicrobial properties, particularly with ozone nanobubbles, which can control the growth of pathogenic microorganisms, thus reducing disease outbreaks in shrimp aquaculture. Nanobubble technology can also contribute to sustainable aquaculture by reducing the accumulation of organic waste, increasing wastewater treatment efficiency, and minimizing the use of antibiotics and chemicals in aquaculture. Moreover, economic evaluations of nanobubble technology have shown that it can increase the profitability of aquaculture farms by increasing harvest productivity and reducing costs in the long term. One major limitation is the relatively high initial cost associated with nanobubble generation equipment compared to conventional aeration systems (Mauladani et al., 2020). Another obstacle is the absence of standard operating procedures for aquaculture applications using nanobubble systems. Recommendations for optimal operating conditions, including bubble size, gas type, and aeration time, are likely to differ based on aquaculture production conditions. Finally, more large-scale field studies are required to further assess the effectiveness and long-term environmental consequences of applying nanobubble technology in commercial aquaculture settings. However, ongoing advancements in technology as well as research into enhancing the cost and/or performance of nanobubble systems will facilitate their use over time.

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ROLE OF e-DNA IN AQUATIC ANIMAL HEALTH

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Regular monitoring and sampling of fish and other aquatic animal for disease investigation is crucial step in aquaculture and conservation of endangered species. But it is difficult to take regular investigation and requires expertise skills. The utilization of e-DNA (environmental DNA) technique becomes a perfect solution for major problems associated with aquatic animal health. It identifies the pathogens like bacteria, virus and parasite in the water sample even the aquatic animal cannot exhibit any clinical signs. Therefore, this method prevents massive loss of stock in aquaculture due to pathogenic infection and mortality of endangered aquatic animal like sea turtle. This method works in low cost and high-throughput period.

Environmental DNA (e-DNA) is the DNA present in the environment and it released from living and dead organism in environmental samples such as water and soil. It has huge potential to monitor the diseases, water-borne virus and protozoan parasite. e-DNA can present in the environment in two forms, either intracellular (such as microorganisms, zooplankton and phytoplankton) or free form from the urine, faeces, saliva, gametes and epidermal cells. Once the DNA is distributed into environment, it can be persisted from hours to week in temperate water and month to year in soil, frozen areas and sediments (Baillie *et al. 2019*)

Steps Involved in E-DNA Sequencing

(i) Collection of sample:

The collection of sample from the ecosystem will depend on the target taxon abundance and total biomass of the ecosystem. Sample from the eutrophic water, sewage effluent and wastewater contain many algae, bacterial and viral species requires small volume of sample due to the high abundance and the high volume of sample is taken while it is collected from the extreme environmental conditions (shaw *et al. 2016*).

(ii) Processing of sample and extraction of e-DNA:

After the sample collection, the sample will be concentrated before DNA extraction. The concentration methods include filtration and centrifugation and any one method can be used (or) combination of these methods used at a time based on the sediment particles in the sample. The extraction of DNA is most widely done by the bead-based mechanical lysis of the cell. This method requires detergents like sodium dodecyl sulphate (SDS) (or) triton-X to breakup membrane structure and lysis and buffer contain salt like EDTA or tris-HCl to regulate osmolality and acidity of extracted solution. The bead beating speed will depend on the sample collected from which type of the environment (shaw *et al. 2016*).

(iii) PCR amplification, design of primer and genetic marker:

It is the step that discriminate the DNA into different taxa group. The primer is designed so that it is equally complementary to any kind of DNA for the efficient and quality amplicons production. The genetic marker is incorporated with primer to discriminate the DNA as whether bacterial or eukaryotic etc. the genetic marker will not discriminate in generic and species level. It only classify into large taxa level like bacteria, fungi, eukaryotes etc. commonly used genetic marker include 16s rRNA for bacteria, 18s rRNA for eukaryotes and ITS for fungi and algae. After primer design and incorporation of genetic marker, amplification of DNA by PCR will be taking place (shaw *et al. 2016*).

(iv) Next generation sequencing (NGS):

It is also known as high-throughput sequencing and non-sanger based methods. It will sequence million of DNA strands in parallelly. This sequence contain sample specific tag (genetic marker) and additionally the platform adaptor sequence is added. This amplified DNA sequence along with sample-specific tag and platform adaptor sequence will be pooled to form "DNA library" in the NGS (next generation sequencing) platform (shaw *et al. 2016*).

(v) Bioinformatic analysis:

The first step include searching of sample-specific tag and separate these sample-specific tag sequence. Discard other sequence and then remove (trim) the sample-specific tag and platform-specific adaptor and then remove low quality sequence and then cluster the similar sequences (also known as operational taxonomic unit (OTU)) and finally compare this OTU with genetic database like genbank, greengenes (bacterial 16s rRNA), SILVA (eukaryotic 16s/18s rRNA) etc. to identify the taxa (shaw *et al. 2016*).

Role of Environmental DNA (e-DNA) in Aquatic Animal Health

The e-DNA based method is used for detecting the pathogenic parasite *Ribeiroia ondatrae* in the north American amphibians to evaluate disease risk. The DNA collected from the environment (e-DNA) is still detectable in lab after 21 days at 25ºC and this method have high advantage and accuracy over the traditional survey methods (Huver *et al.* 2015)

The key advantage of e-DNA is early detection of parasitic infection in water using e-DNA technique even the fish cannot exhibit any clinical signs in order to avoid disease outbreak (Gomes *et al.* 2017a).

Peters *et al.* (2018) develops a e-DNA metabarcoding tool using lon torrent sequencing for detecting the pathogens in salmonid aquaculture. They identify the two parasites *Lepeophtheirus salmonis* and *Paramoeba perurans* to species level.

Pawlowski *et al.* (2014) also used metabarcoding tool based on next-generation sequencing of e-DNA and RNA for detecting the impact of aquaculture and other industrial activities in marine ecosystem by comparing the foraminiferans species richness between fish farming environment and other environment.

Fong *et al.*(2016) uses environmental DNA to detect the seasonality and pathogenicity (virulence) of the *Aeromonas* bacterial strain from water samples of different waterways of Korea.

Farrell *et al*. (2021) uses the environmental DNA to detect the viral transmission in sea turtle. Chelonid herpes virus 5 (ChHV5) causes fibropapillomatosis in sea turtle and they identified that the transmission of ChHV5 through water column rather than marine leeches using e-DNA technique.

Gomes *et al*. (2017b) uses environmental DNA and water quality data to detect the protozoan parasite *Chilodonella hexasticha* as a model in *Lates calcarifer* fish farm and water was sampled in one year time interval and they identified that there is no correlation between water and parasite abundance.

Brannelly *et al*. (2020) uses e-DNA for detecting an amphibian pathogen *Batrachochytrium*. They examined the soil sample and water sample to compare the efficiency of e-DNA technique for pathogen detection in two different environments. They conclude that detection of e-DNA in water sample give better result than soil sample.

Conclusion

Environmental DNA (e-DNA) is a novel approach to diagnose the pathogenic infection in aquatic environment. It gives curate result that is similar to traditional methods. The e-DNA methods not only used in aquatic animal health, but also have huge applications including biodiversity monitoring, organism abundance, population genetics, sustainable aquaculture, stock assessment and detection of aquatic invasive species (Baillie *et al. 2019*).

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A STUDY ON THE ROLE OF YOUTH PARTICIPATION IN AGRICULTURE AND EXTENSION SERVICES IN ENHANCING SUSTAINABLE AGRICULTURAL DEVELOPMENT

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Youth involvement in agriculture and extension activities is crucial for ensuring sustainability and modernization. With challenges like climate change, declining farm income, and rural-urban migration, engaging youth has become essential. Young people contribute innovation, energy, and readiness to adopt modern technologies such as digital tools, precision farming, and climate-smart practices. Agricultural extension services empower youth by providing technical knowledge, training, and linking them with research and markets, fostering entrepreneurial skills. However, barriers like limited access to land, credit, and negative perceptions persist. Strengthening extension systems, promoting agri-entrepreneurship, and integrating ICTs can enhance youth participation, boosting productivity, rural development, and employment generation.

Although it employs about half of India's workers, agriculture only makes up around one-fifth of the country's GDP (Sen, 2025). According to Kumar and Dhingra (2024), rural young are a demographic dividend since they are more literate than previous generations, willing to embrace innovations, and in a unique position to revolutionise agriculture through technology and entrepreneurship. However, a growing number of young people are migrating to cities in search of non-farm employment, and many farmers are over 50 (Chakraborty et al., 2025). Redesigned extension systems that provide timely information, develop capabilities, and connect young people to institutions and markets are necessary to overcome these limitations. (Mukhopadhyay, 2024). Extension today includes farmer groups, entrepreneurship, value chain development, and policy advocacy in addition to technology dissemination. Another change is required for youth engagement: extension needs to be youth-focused, tech-savvy, and entrepreneurial. According to empirical research, extension workers use mobile phones, internet advisories, and social media more than computers, televisions, or projectors as information and communication technology (ICT) tools (Prasad & Pradhan, 2019).

Importance of Youth in Agriculture

A significant source of energy for the entire food supply chain in the agricultural industry is youth. From the seed to the consumer, they are essential to the production of food crops. Youth have a major role in the post-harvest phase. The advanced, practical outcomes in the field of agriculture are the responsibility of the young people working in research sectors

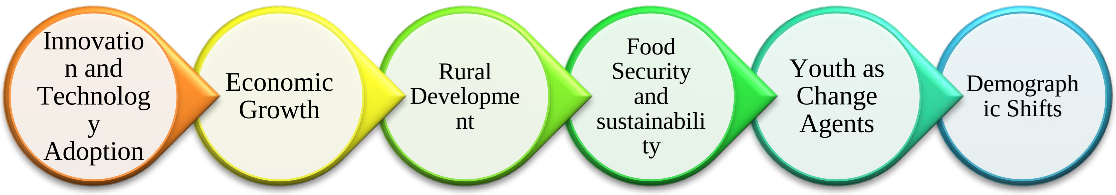


Fig. 01: Role of Youth in Driving Agricultural Development and Transformation

Youth Engagement and Empowerment in Agriculture

Youth engagement and empowerment in agriculture is the process of involving young people actively in agricultural activities and strengthening their capacity through education, skills, resources, and institutional support to enhance their decision-making ability, productivity, and livelihood security.

Fig. 2: Youth Engagement in Agriculture and Extension in BAU, Sabour Activities

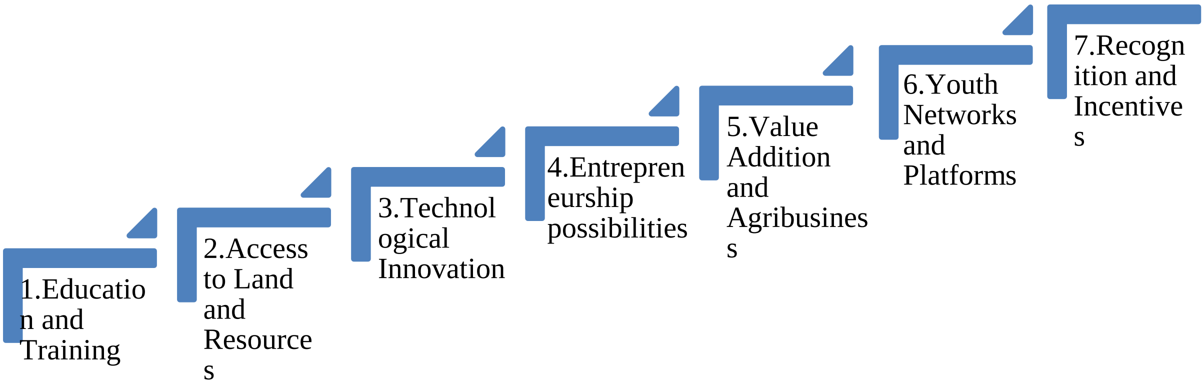


Fig. 3: Key Factors Enhancing Youth Participation in Agriculture

Role of Agricultural Extension Services

Agricultural extension programs are essential for empowering farmers and improving their expertise. These extension programs work as links between actual farming and scientific research by offering training, teaching, and advising services. The prosperity and sustainability of an agricultural environment that is always changing. The resources, expertise, and information that farmers possess are crucial to farming communities. Agricultural extension services play an increasingly important role in helping farmers increase their knowledge and skills so they may better adjust to changing conditions, enhance their livelihoods and production, and improve their practices.

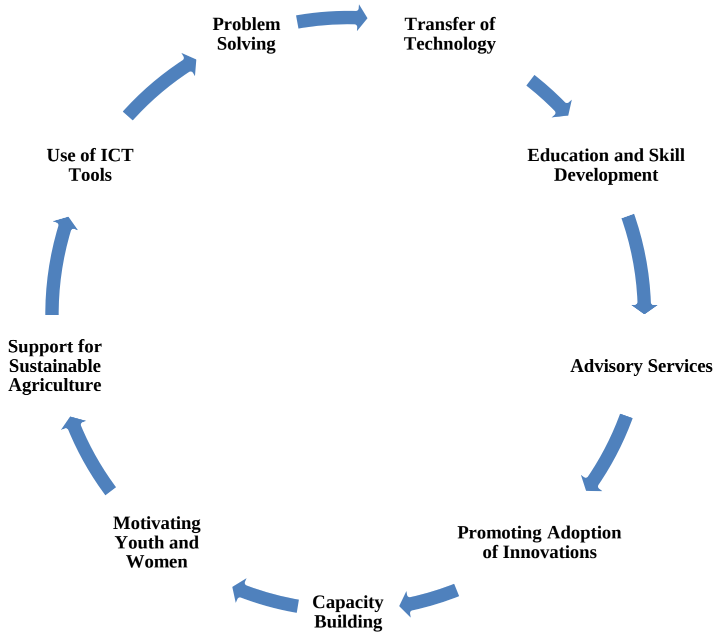
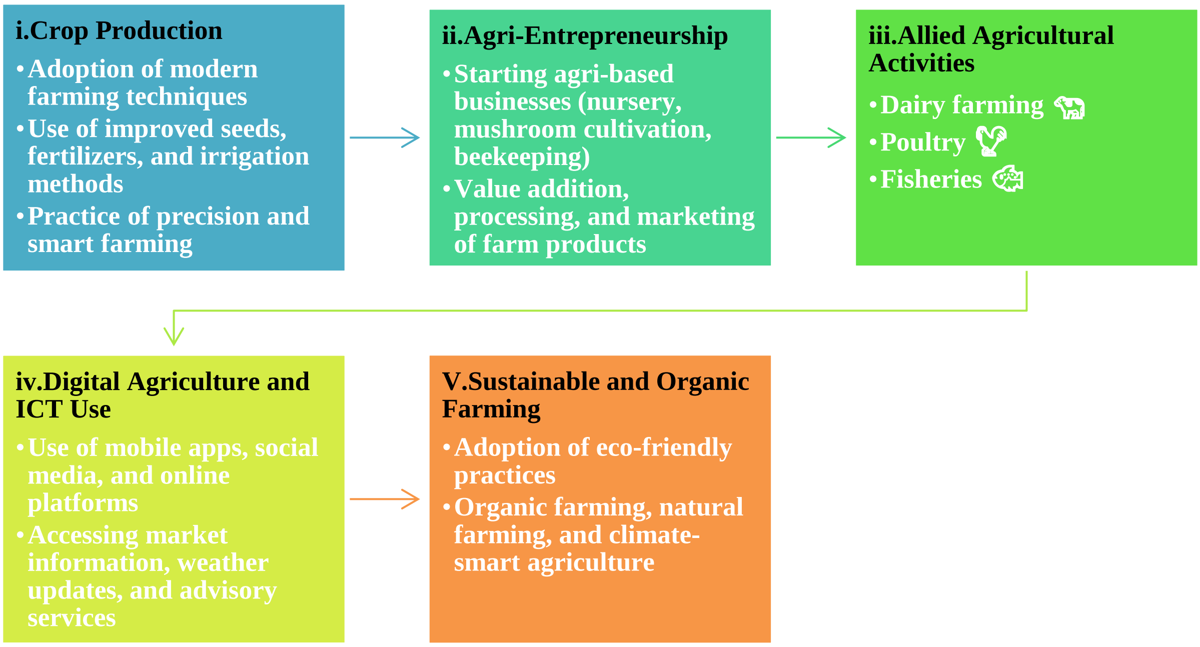


Fig. 4: Cycle of Youth Empowerment and Sustainable Development

Areas of Youth Participation

- The various agricultural and extension service sectors or fields where young people actively participate, contribute, and use their abilities, expertise, and creativity are referred to as "areas of youth participation." Crop production, agri-entrepreneurship, Allied Agricultural Activities, digital technology use, Sustainable and Organic Farming and agricultural marketing are some of the areas where young people promote rural transformation and agricultural growth.



Conclusion

The engagement of youth is necessary for the sustenance and advancement of agricultural practices. The innovative nature and open-mindedness towards new technologies will help tackle issues such as climate change and low earnings from farms. Agricultural extension services will help the youth participate in agriculture by providing education and information about markets. There are constraints like scarcity of funds and unfavourable attitudes, but improvements in extension services and agri-entrepreneurship will facilitate youth participation.

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SCALY LEG MITE INFESTATION (*Knemidocoptes mutans*) IN POULTRY

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Scaly leg mite infestation, commonly termed Knemidocoptic mange or "tassel foot," is a chronic parasitic skin disease of poultry caused by the burrowing mite *Knemidocoptes mutans*. The condition primarily affects the unfeathered portions of the legs and feet of chickens, although turkeys, pheasants and several wild avian species may also be affected (Sreedevi *et al*., 2015 and Shehata *et al*., 2025). The disease is encountered more frequently in backyard and smallholder poultry systems where hygiene, nutrition, and ectoparasite control are often inadequate. Chronic infestations compromise bird welfare and may result in hyperkeratosis, lameness, secondary bacterial infections, reduced productivity, and permanent deformity of digits if neglected (Morishita *et al*., 2005). The MSD Veterinary Manual describes *K. Mutans* as a mite that "tunnels into the tissue under the scales of the bird's legs," producing progressive crusting and thickening of the legs.

Etiology and Epidemiology

Knemidocoptes mutans is a microscopic burrowing mite belonging to the family Epidermoptidae. The complete life cycle occurs on the host bird, generally within 10–14 days. Transmission occurs mainly through direct contact between infected and healthy birds. Contaminated litter, wooden perches, nesting material and poorly sanitized housing may facilitate spread within the flock (MSD Veterinary Manual, 2025).

Predisposing factors include:

Poor sanitation, damp housing conditions, nutritional deficiencies, overcrowding, chronic stress, advanced age and lack of ectoparasite control.

Recent investigations in indigenous poultry systems demonstrated that *K. Mutans* continues to be an important ectoparasite in scavenging birds maintained under rural production systems (Nadia *et al*., 2025).

Pathogenesis

The pathogenic effects arise from continuous burrowing activity beneath the keratinized epidermal scales. Mechanical irritation caused by the mites induces chronic inflammation, serous exudation and excessive keratin production, ultimately leading to hyperkeratosis and scale elevation (Shanta *et al*., 2006). Affected legs gradually develop rough, thickened, crusty lesions with accumulation of whitish-gray debris beneath the scales. In advanced cases, lesions interfere with joint flexion and locomotion, producing lameness and deformity (Ikpeze *et al*., 2008; Sreedevi *et al*., 2015). *Morishita et al.* (2005) documented severe infestations associated with "digit necrosis" in bantam chickens, highlighting the chronic and progressive nature of untreated disease.

Clinical Signs

Clinical signs generally develop gradually over several weeks or months. Common findings include:

- Raised and thickened leg scales
- Whitish or grayish powdery lesions
- Hyperkeratotic crusts
- Rough, honeycomb-like appearance of the legs
- Irritation and pecking at affected areas
- Pain while walking or perching
- Reluctance to move
- Progressive lameness
- Deformed or necrotic toes in chronic cases
- Reduced body condition and egg production

 

Diagnosis

Diagnosis is usually based on characteristic clinical appearance and flock history. Confirmation can be achieved by microscopic examination of skin scrapings obtained from beneath affected scales, where mites, eggs, or developmental stages may be demonstrated (Sreedevi *et al*., 2015).

Differential diagnoses include:

Favus (fungal dermatitis), Nutritional dermatoses, Chronic bacterial dermatitis, Frostbite lesions and Hyperkeratotic skin disorders

Treatment and Field Management

Successful treatment requires elimination of mites together with correction of environmental and nutritional factors. In practical field conditions, topical management remains economical and effective, particularly in backyard poultry. Soft soap cleansing followed by application of petroleum jelly (vaseline) has shown satisfactory clinical improvement in many cases. Gentle scrubbing helps soften crusts and remove accumulated debris, while vaseline acts by occluding mite burrows and limiting parasite survival beneath the scales.

Repeated applications are generally necessary because mites remain protected within hyperkeratotic lesions. Supportive supplementation and correction of nutritional deficiencies further aid tissue repair and recovery in debilitated birds.

Traditional occlusive therapy continues to be widely recommended. The British Hen Welfare Trust notes that thick application of vaseline helps "suffocate the mites and soften the scales." (British Hen Welfare Trust) In moderate to severe infestations, ivermectin therapy may be administered under veterinary supervision. Sreedevi *et al*. (2015) reported successful therapeutic management of *K. Mutans* infestation using ivermectin in backyard poultry.

Environmental sanitation is essential to prevent reinfestation:

- Thorough cleaning and disinfection of poultry houses
- Replacement of contaminated litter
- Treatment of wooden perches and nest areas
- Isolation of severely affected birds
- Reduction of overcrowding
- Prevention of contact with infested birds and wild carriers

Integrated ectoparasite management strategies are recommended for sustainable control in poultry systems (*Sparagano et al.*, 2020).

Prevention

Preventive measures include:

- Maintenance of dry and hygienic housing
- Routine ectoparasite monitoring
- Quarantine of newly introduced birds
- Balanced nutrition and mineral supplementation
- Avoidance of overcrowding and chronic stress
- Regular inspection of legs, particularly in older birds

Early detection and prompt intervention substantially reduce chronic deformities and production losses.

Conclusion

Scaly leg mite infestation caused by *Knemidocoptes mutans* remains an important chronic ectoparasitic disease of poultry, particularly in backyard poultry characterized by hyperkeratosis, crusting, scale elevation, lameness and progressive deformity of the legs and feet. Early diagnosis, environmental sanitation, supportive therapy, and effective mite control are essential for successful management. Practical field approaches such as soft soap cleansing, vaseline application, nutritional supplementation, and improved flock management continue to provide economical and effective control under rural poultry conditions.

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AGRI- STARTUPS IN MODERNIZING AGRICULTURE AND IMPROVING FARM INCOME UNDER A CHANGING CLIMATE

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Climate change has become one of the greatest challenges facing global agriculture in the 21st century. Agriculture is highly dependent on climatic conditions such as temperature, rainfall, humidity, and solar radiation. Any variation in these climatic factors directly affects crop growth, livestock productivity, soil fertility, and water availability. In recent years, the world has witnessed rising temperatures, erratic rainfall, frequent droughts, floods, cyclones, and heat waves due to climate change. These changes are adversely affecting agricultural production and productivity, threatening food security and farmers' livelihoods, particularly in developing countries like India, where agriculture is the backbone of the rural economy (Birthal et al. 2014). Indian agriculture is highly vulnerable to climate variability because a large proportion of cultivated land is rainfed and dependent on the monsoon. Delayed onset of monsoon, uneven rainfall distribution, prolonged dry spells, and unseasonal rainfall during harvesting stages often lead to severe crop losses.

Increasing temperatures accelerate evapotranspiration and reduce soil moisture, which negatively affects crop growth and yield. Heat stress during the flowering and grain filling stages reduces the productivity of crops such as wheat, rice, soybean, and maize. Similarly, changes in climate also increase the incidence of pests, diseases, and weeds, resulting in higher crop protection costs and reduced farm profitability (Swami et al. 2018). Climate change also affects natural resources that are essential for agriculture. Declining groundwater levels, deterioration of soil health, nutrient depletion, and reduced biodiversity are major concerns. Livestock production is equally affected due to heat stress, reduced fodder availability, and increased disease outbreaks. Fisheries and horticultural crops are also facing serious challenges because of changing environmental conditions. As a result, farmers are experiencing unstable yields, reduced income, and increased economic risk. Small and marginal farmers are the most vulnerable because they have limited access to irrigation, technology, quality inputs, and institutional support (Oishy et al. 2025).

Role of Agri-Startups in Agricultural Transformation

In this challenging scenario, startups are emerging as important agents of change in modernizing agriculture and improving farmers' income. Agri-startups are using innovation, digital technologies, and scientific approaches to solve agricultural problems and make farming more resilient, productive, and profitable. These startups are bridging the gap between research institutions and farmers by delivering practical, affordable, and location-specific solutions.

Precision Agriculture and Digital Climate Advisory Services

One of the major contributions of startups is in the field of precision agriculture. By using technologies such as drones, sensors, artificial intelligence (AI), satellite imaging, and Internet of Things (IoT), startups help farmers monitor crop health, soil moisture, nutrient status, and pest infestation in real time. This enables farmers to apply water, fertilizers, and pesticides more efficiently, reducing input costs and increasing productivity. Precision farming also minimizes environmental pollution and promotes sustainable use of natural resources. Weather forecasting and climate advisory services provided by startups are highly beneficial for farmers. Mobile-based applications and digital platforms provide timely information on rainfall, temperature, humidity, pest outbreaks, and suitable crop management practices. Such advisories help farmers make informed decisions regarding sowing, irrigation, fertilizer application, and harvesting, thereby reducing climate-related risks (Aijaz et al. 2025 and Chen 2025).

Climate-Resilient Technologies and Sustainable Farm Practices

Startups are also promoting climate-resilient agricultural practices such as protected cultivation, hydroponics, organic farming, natural farming, conservation agriculture, and efficient irrigation methods like drip and sprinkler irrigation. These technologies improve resource-use efficiency, conserve water, and enhance productivity under adverse climatic conditions. Many startups are developing stress-tolerant seed varieties and bio-inputs that help crops withstand drought, salinity, and pest attacks.

Market Linkages and Supply Chain Management

Another important role of startups is improving market linkages and supply chain management. Digital marketing platforms connect farmers directly with consumers, retailers, processors, and exporters, reducing the role of middlemen and ensuring better prices for farm produce. Startups also help in aggregation, grading, packaging, cold storage, and transportation, which reduce post-harvest losses and improve profitability. E-commerce platforms and farmer producer organizations (FPOs) supported by startups are empowering farmers with better bargaining power and market access.

Agri-Fintech, Risk Management and Rural Entrepreneurship

Financial and insurance services offered by agri-fintech startups are also helping farmers manage risks and improve investment capacity. Digital credit facilities, crop insurance, mobile banking, and online payment systems provide easy access to financial support and reduce dependency on informal credit sources. Some startups are also facilitating carbon credit programs and sustainable farming certifications, which create additional income opportunities for farmers. Furthermore, startups are creating employment opportunities in rural areas through entrepreneurship, agri-services, custom hiring centers, and input supply chains. Youth involvement in agri-startups is encouraging modernization of agriculture and attracting educated individuals towards farming and agribusiness. Collaboration among startups, government agencies, research institutions, and private organizations can accelerate agricultural transformation and strengthen climate resilience (Amit et al. 2024, www.startupindia.gov.in).

Conclusion

Agri-startups play a critical role in advancing climate-resilient and income-oriented agriculture by integrating digital technologies, precision input management, climate advisories, bio-inputs, market linkages, and agri-financial services. These innovations can improve resource-use efficiency, reduce production and market risks, minimize post-harvest losses, and enhance farm profitability. Their wider impact, however, depends on affordability, scalability, farmer capacity building, and strong convergence among startups, research institutions, FPOs, government agencies, and private stakeholders.

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BALANCED USE OF FERTILIZERS: KEY TO SOIL HEALTH, PRODUCTIVITY, AND SUSTAINABILITY

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Agriculture is the backbone of the Indian economy, and fertilizers have played a pivotal role in enhancing food grain production over the past several decades. The Green Revolution revolutionized Indian agriculture through the widespread adoption of high-yielding crop varieties supported by irrigation and increased use of fertilizers. However, continuous and indiscriminate application of high-analysis fertilizers, particularly nitrogenous fertilizers such as urea, has led to serious concerns, including deterioration of soil health, nutrient imbalance, declining factor productivity, and environmental pollution. In the present context of climate change, escalating input costs arising from global conflicts and energy crises, and rapid degradation of natural resources, the balanced use of fertilizers has become crucial for ensuring sustainable agricultural production and long-term soil fertility (Eliazer et al. 2019, Singh et al. 2021).

Concept and Importance of Balanced Fertilisation

Balanced fertilisation refers to the judicious application of essential plant nutrients in optimum proportions based on crop requirements, soil nutrient status, and targeted productivity levels. Crop plants require adequate supplies of primary macronutrients, namely nitrogen (N), phosphorus (P), and potassium (K), in addition to secondary nutrients such as sulphur (S), calcium (Ca), and magnesium (Mg), along with micronutrients including zinc (Zn), boron (B), iron (Fe), manganese (Mn), copper (Cu), and molybdenum (Mo) for normal growth, metabolic activities, and reproductive development. An imbalance in nutrient supply, whether through deficiency, excess, or disproportionate application, adversely affects nutrient uptake, physiological processes, crop productivity, and produce quality. Consequently, balanced nutrient management is recognized as a critical component for sustaining soil health, enhancing nutrient use efficiency, improving crop productivity, and ensuring the long-term sustainability of agricultural production systems (Khambalkar et al. 2025).

Balanced Fertilization for Soil Health

Healthy soil is the basis of sustainable crop production. Balanced fertilization helps maintain soil fertility by replenishing nutrients removed by crops. It improves soil physical, chemical, and biological properties. Application of organic manures such as farmyard manure (FYM), compost, vermicompost, crop residues, and green manures, along with chemical fertilizers enhances soil structure, water-holding capacity, and microbial activity. Integrated Nutrient Management (INM), which combines inorganic fertilizers with organic and biological sources, is considered an effective approach for maintaining long-term soil productivity (Kumar et al. 2025).

Nutrient Use Efficiency and 4R Nutrient Stewardship

Balanced fertilizer use is fundamental to enhancing nutrient use efficiency and minimizing nutrient losses from agricultural systems. A substantial proportion of applied nutrients is often lost through processes such as leaching, surface runoff, volatilization, denitrification, and soil fixation, thereby reducing fertilizer efficiency and increasing environmental risks. Adoption of scientifically sound nutrient management practices, including soil test-based fertilizer recommendations, site-specific nutrient management, split application of nitrogenous fertilizers, deep placement techniques, fertigation, and the use of coated, stabilized, or slow-release fertilizers, can substantially improve nutrient recovery and crop uptake efficiency. In this context, the “4R Nutrient Stewardship” framework—application of the right nutrient source, at the right rate, at the right time, and in the right place—has emerged as a globally accepted strategy for optimizing fertilizer use efficiency, sustaining crop productivity, and reducing the environmental footprint of intensive agricultural systems (Mikkelsen, 2011).

Micronutrient Management and Nutritional Quality

Micronutrient deficiencies are emerging as a major challenge in Indian agriculture. Deficiencies of zinc, sulphur, boron, and iron are increasingly reported in intensively cultivated soils. Though required in small quantities, micronutrients play critical roles in plant growth, enzyme activity, flowering, seed formation, and crop quality. Balanced fertilization involving both macro and micronutrients is therefore essential for sustaining productivity and improving nutritional quality of agricultural produce (Verma et al. 2025).

Economic Benefits and Policy Support

Economic benefits to farmers are another important advantage of balanced fertilization. Fertilizers constitute a major component of cultivation cost. Unscientific and excessive use not only increases production costs but also reduces profitability. Soil test-based nutrient management helps farmers apply only the required amount of fertilizers, thereby reducing unnecessary expenditure and improving returns. Balanced fertilization also improves crop quality, market value, and overall farm income. Government initiatives such as the Soil Health Card Scheme, promotion of nano fertilizers, customized fertilizers, and awareness programmes on Integrated Nutrient Management are encouraging farmers to adopt balanced fertilizer practices. Advances in precision agriculture, remote sensing, drones, and digital advisory services are also creating new opportunities for efficient nutrient management (Goyal et al. 2023, Kumar et al. 2025).

Challenges and Way Forward

Despite these efforts, several challenges remain. Lack of awareness among farmers, inadequate soil testing facilities, rising prices of phosphatic and potassic fertilizers, and limited availability of organic inputs are major constraints in balanced fertilizer use. Strengthening extension services, farmer training programmes, and easy access to soil testing and nutrient advisory services are essential for wider adoption of balanced nutrient management practices.

Need for Integrated and Balanced Nutrient Management

Therefore, balanced use of fertilizers is the key to maintaining soil health, enhancing crop productivity, improving nutrient use efficiency, and ensuring environmental sustainability. Sustainable agriculture cannot be achieved through excessive dependence on chemical fertilizers alone. Integrated and balanced nutrient management involving chemical fertilizers, organic manures, crop residues, and biofertilizers is the need of the hour. Farmers, scientists, policymakers, and extension agencies must work together to promote balanced fertilization practices for ensuring long-term food security, profitability, and conservation of natural resources.

Conclusion

Balanced fertilization is a central requirement for sustaining soil fertility, nutrient-use efficiency, crop productivity, and environmental quality in intensive agricultural systems. The integration of soil test-based fertilizer application, organic nutrient sources, biofertilizers, micronutrient management, and 4R nutrient stewardship can correct nutrient imbalances, reduce nutrient losses, improve soil biological functioning, and enhance farm profitability. Therefore, balanced and integrated nutrient management should be promoted as a key strategy for achieving sustainable intensification, climate-resilient production, and long-term food and nutritional security.

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