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REVIEW

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Harmony in Agriculture: Integrating Horticulture and Fish Farming for Sustainability

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Conflict of Interest
The authors declare that the manuscript was formulated in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Authors Contribution
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Abstract
Integrated fish horticulture farming maximizes resource utilization by repurposing waste into valuable products. It involves cultivating fruits, vegetables, and flowers alongside fish ponds. Given the nutritional benefits of fruits and vegetables, especially in India where daily intake goals are emphasized, integrating fish and horticulture could address the challenges faced by the majority of small-scale farmers. By diversifying crops and optimizing water use, this approach boosts production, nutrition, profits, and rural employment. Farmers prioritize sustainable input supply and efficient site design for successful implementation. This model not only enhances sustainability but also allows farmers to produce nutrient-rich goods, reduce costs, and increase yields per unit area. Horticultural crop production, aquaculture, and livestock farming are recognized as financially rewarding sectors, driven by consumer demand for healthy diets. Focusing on these sectors aligns with the Prime Minister's objective of doubling farmers' income by 2022.

KEYWORDS
Synergistic Farming, Optimal Resource Use, Aquaculture Farming, Sustainable Agriculture, Rural Prosperity.

INTRODUCTION

In the present era, the economy is predominantly driven by agriculture and Information Technology, specifically in software development. To accelerate development in rural regions, our focus should prioritize the conservation of natural resources, efficient resource allocation, enhanced productivity and profitability, and improved quality and competitiveness by reducing production costs per unit. India's abundant freshwater resources, including lakes and rivers, offer significant potential. Research indicates that the number of fish species in these bodies of water may surpass 200 (Jerbe, 2007). The management of water resources is becoming an international challenge, and its efficient handling and recycling have been prioritized in strategic planning (Singh et al., 2023).

Aquaculture, a component of horticulture, entails the regulated cultivation of aquatic organisms, encompassing fish, plants, and animals. Integration of fish culture with livestock and horticulture, especially in vegetable farming, allows for the recycling of waste from one component to serve as input for another, thereby promoting organic production. Aquaculture significantly contributes to meeting the global demand for fish as food, helping to alleviate poverty and foster rural development, emerging as the fastest-growing segment in global food production. Integrated aquaculture combines different horticultural systems with aquaculture, anticipating synergistic effects on resource conservation and productivity. Integrated Fish Farming exemplifies mixed farming, integrating fish polyculture with horticulture or livestock production. On-farm waste recycling, integral to this approach, enhances production economics and reduces environmental impact. Integrating aquaculture with livestock or crop farming not only supplies quality protein but also maximizes resource use, promotes waste recycling, creates jobs, and fosters economic development. Pond management integrating poultry, fish, and vegetables has demonstrated effectiveness in achieving sustainable production, generating income, and creating employment opportunities for resource-poor rural households (Alam et al., 2009). Adding organic fertilizers like poultry droppings to fish ponds has been shown to improve fish production (Enamul Hoq et al., 1999; Abbas et al., 2004). Addressing challenges in fish feed for aquaculture development can be achieved through the integration of fish farms with poultry. Integrated fish farming aims to minimize production costs and maximize output by combining previously separate systems. This approach optimizes the use of horticultural by-products, increasing returns per unit of land area and providing farmers with higher disposable income. Additionally, it mitigates the risk of production failure by diversifying production activities and enhances the nutritional profile of rural inhabitants by increasing access to animal proteins. Integrated fish farming systems include integrated horticulture-aquaculture (AA), integrated animal husbandry-aquaculture (AA), and integrated animal husbandry-horticulture-aquaculture (AAA).

HISTORY OF INTEGRATED FISH FARMING:

Asia has a rich and diverse history of integrated fish farming, with documented evidence dating back to the first and second centuries B.C. Early records highlight the integration of aquatic plant cultivation with fish farming. By the ninth century, fish farming in paddy fields became evident. From the fourteenth to sixteenth centuries, there was a shift towards rotating fish and grass culture. By the 1620s, more sophisticated systems emerged, such as the mulberry-dike fishpond, integrating fish and livestock farming, alongside complex setups combining multiple enterprises with fish farming. Integrated fish farming methods include culturing fish alongside paddy fields, piggeries, poultry, livestock, or flower cultivation.

PURPOSE OF INTEGRATION:

Fish production serves a crucial role in integrated farming systems by providing cost-effective feed ingredients and organic matter serve as nourishment for fish ponds. This decreases dependence on costly formulated fish feeds and synthetic fertilizers. Consequently, lowering the overall cost of fish production and increasing profits. Integration can boost fish culture profits by 30-40 percent. Moreover, integrated rearing of pigs and/or poultry, cultivating grains, and growing vegetables, among other activities, alongside fish farming contributes to an overall increase in income. This diversified approach not only enhances financial gains but also promotes self-sufficiency within the community by producing a variety of food products, including grains, vegetables, fish, and livestock. This multi-pronged approach fosters significant self-sufficiency. The sediment from fish ponds, employed as fertilizer for crops, enhances crop yields at a lower cost, reducing the reliance on chemical fertilizers. Roughly one-third of the nation's agricultural fertilizer requirements are supplied by fish ponds. Moreover, freshwater pearl production within these ponds offers an extra revenue stream, enhancing the economic sustainability of integrated fish farming systems.

PRINCIPLES OF INTEGRATED FISH FARMING:

Integrated fish farming is founded on the principle that waste is not inherently wasteful but rather a resource that can be repurposed for another use (Soni et al., 2014; Csavas, 1991). This approach emphasizes harnessing the synergies between different farm activities and maximizing resource utilization, including the effective management of farm wastes. The assumption is that all components of the system stand to benefit from such a combination, although in many cases, fishes emerge as the primary beneficiaries, directly or indirectly utilizing animal and agricultural wastes as food. The recycling of wastes in integrated farming is seen as an economical and efficient method of environmental management.

KEY FEATURES OF INTEGRATED FISH FARMING INCLUDE:

- Nutrient Cycling: Nutrients from one biological system are repurposed to nourish a second biological system.
- Polyculture: Combining fish and plants leads to a diverse polyculture that boosts variety and generates multiple products.
- Water Recycling: Water undergoes biological filtration and recirculation, facilitating effective water management through its reuse.
- Local Food Production: The local production of food not only provides access to healthy foods but also contributes to the enhancement of the local economy.

These principles highlight the holistic and sustainable nature of integrated fish farming, emphasizing the interconnectedness of various farming activities to maximize resource utilization and minimize waste.

ECOLOGICAL DYNAMICS OF INTEGRATED FISH FARMING:

The ecosystem of integrated aquaculture involves a complex interplay of various sub-systems, as depicted in a schematic diagram illustrating the major interactions in a crop-livestock-fish integration farming system (Edwards, 1993).

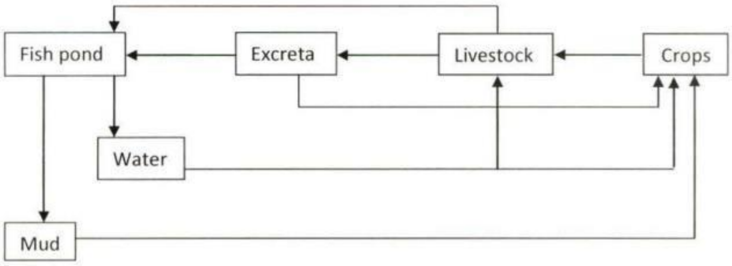

Fig 1: Schematic diagram illustrating the interactions in a crop – livestock – fish (Edwards, 1993).

Integrated fish farming involves several key steps:

- Capturing solar energy through a specific process.
- Generating organic material by primary producers (autotrophs).
- Utilizing this organic material by phagotrophs.
- Decomposing autotrophs and phagotrophs through saprotrophs.
- Releasing nutrients that benefit autotrophs.

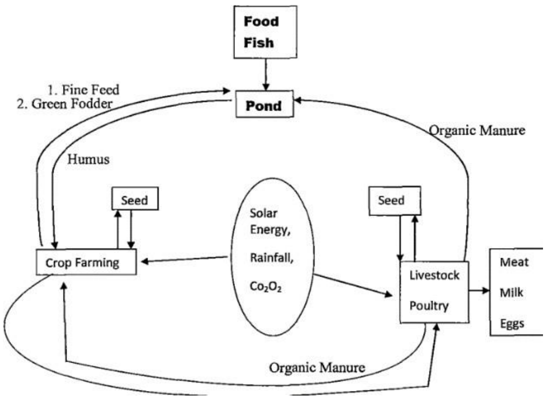

Fig 2: Material recycling is an integral aspect of a well-managed integrated fish farm, as outlined in NACA Technical Manual 7 (1989).

BENEFITS OF INTEGRATED FISH FARMING:

- Integrated fish farming efficiently utilizes waste from various cultural practices, reducing the need for supplementary feeding and fertilization, creating an artificial balanced ecosystem with minimal waste.
- This approach not only lowers costs but also enhances economic efficiency by reducing inputs and increasing outputs, providing more employment opportunities.
- The system offers a diverse range of products, including fish, meat, milk, vegetables, fruits, eggs, grains, fodder, and mushrooms, contributing to increased production and improved socio-economic status, particularly for marginalized communities.
- Additional income is generated through the cultivation of fruits and vegetables on pond embankments, typically unused land.
- The fertile pond mud, rich in nutrients, acts as an economical crop fertilizer, eliminating the necessity for organic manures.
- Manure-enriched pond water is utilized for plant irrigation, while leftover fruit and vegetable residues are repurposed as valuable fish feed, establishing a sustainable cycle.
- The presence of plants on the embankment not only strengthens dikes but also adds to the overall ecological balance of the integrated fish farming system.

HORTICULTURE FISH INTEGRATION SYSTEM:

The horticulture-cum-fish farming system involves cultivating fruits, vegetables, and flowers on the pond embankment. Fruits and vegetables are rich in essential nutrients, aligning with the Indian Council of Medical Research's daily recommendations. Utilizing both inner and outer dykes for horticulture crop production, the success hinges on selecting dwarf, seasonal, evergreen, and remunerative plants. Fruit crops like Mango, Banana, Papaya, and vegetables such as Brinjal, Tomato, and Cucumber are grown year-round. Flower plantations including Rose, Jasmine, and Marigold add beauty and income. This integrated system yields 20-25% more returns than aquaculture alone.

- Efficiently utilizing pond dykes and adjoining areas for horticulture crops.
- Employing pond water for irrigation and nutrient-rich bottom silt as manure for various crops, vegetables, and fruit plants.
- Success dependent on choosing dwarf, less shady, evergreen, seasonal, and lucrative plants.
- Suitable crops include dwarf mango, banana, papaya, coconut, lime, with intercrops like pineapple, ginger, turmeric, and chilli.
- Growing vegetables such as cauliflower, cabbage, brinjal, tomato, cucumber, and various legumes.
- Cultivating flowering plants such as rose, jasmine, lily, gladiolus, marigold, and chrysanthemum to supplement farmer income.
- Significant cost reduction (50%) by minimizing the purchase of manures and fertilizers.

PROCEDURE FOR ESTABLISHMENT OF INTEGRATED FISH HORTICULTURE SYSTEM:

- Choose ponds in close proximity to your residence for convenient management and to deter poaching.
- Regularly check and repair dikes, and install meshed screens on inlets and outlets to prevent fish from escaping and unwanted species from entering.
- Ensure the pond has sufficient depth to retain more than 1 meter of water during dry periods.
- Reinforce and terrace the dikes for planting crops and fruit plants.

PREPARATION OF POND:

Eliminate aquatic weeds and compost them to produce pond manure. Eliminate existing fish stock through repeated netting and pond water draining. If draining isn't possible, add 15 kg bleaching powder and 15 kg urea (for 1,000 m^2 pond) to kill fishes; bleaching powder can follow urea application. Alternatively, use 250 kg Mahua oil cake mixed thoroughly with pond water and net the fishes. Manure the pond with compost, applying 500 kg initially and the remaining 500 kg in two equal installments at 4-month intervals (or more frequent doses). Stock the pond with fingerlings 7 days after poisoning, adjusting stocking density based on pond conditions and fish seed availability.

ESTABLISHING HORTICULTURAL CROPS:

Strengthen, terrace, and fertilize pond dikes with pond silt, cultivating bananas, papayas, pumpkins, gourds, spinach, brinjals, tomatoes, cucumbers, and leafy vegetables. Apply inorganic fertilizer at 10 kg/year in installments. Water the crops with pond manure. Plant papaya in June/July and banana in October/November, with harvesting beginning 6 and 8 months later. The farmer consumes a portion, selling the remainder. Vegetable crops are harvested twice yearly—August/September and March/April—meeting family needs before selling the surplus.

Banana: Banana (Musa spp) is highly compatible with fish farming integration, providing various benefits when planted on pond dykes. After banana harvest, vertically cutting and introducing the stems into ponds, then lifting them after partial decomposition, reduces water turbidity and increases alkalinity (Tamuli et al., 2010). Assamese people traditionally burn banana spadix during winter, using the ash called "khar" as a curry additive or pH neutralizer in aquaculture instead of lime. Banana also serves to protect new embankments from erosion. The green leaves are suitable as food for herbivorous fish like grass carp. Planting a row of semi-tall bananas around a one-bigha pond yields approximately 30 quintals of bananas in the first year.

Papaya, both a popular fruit and vegetable crop, proves suitable for pond embankments due to minimal shading and fish-friendly characteristics. Pond mud serves as excellent manure for papaya trees. Plant month-old saplings in April-May at a spacing of 1.8m x 1.8m in pits of 45 cm x 45 cm x 45 cm. Apply 500 g each of manure, and NPK fertilizer in two splits for optimal growth. High-yielding varieties like Swapna, Red Lady, and Sinta are recommended. Harvesting around 30-40 kg of papaya from one fruiting plant is achievable in the first year. Integrated farming systems have demonstrated fruit production of 650.00 kg in papaya plants, providing additional income from poultry and papaya within the same space, along with fish production (Sharma et al., 2016).

Pineapple cultivation on pond dykes is favorable due to the well-drained nature of these areas. Propagation can be done through suckers, slips, and crowns, with local varieties like Kew and Queen being suitable. Planting material typically bears flowers after 12 months (except crowns, which take 19-20 months) and is arranged in two-row beds, with a spacing of 60 cm between rows and 30 cm between plants. Harvesting occurs when fruits turn yellow. Planting two rows of pineapple around a one-bigha pond yields approximately 5 quintals of pineapple in the first 1.5 years (Bhuyan and Neog., 2018).

Turmeric, also known as haaldi in India, is a rhizomatous herbaceous perennial plant with rhizomes widely used as a spice and color enhancer in Asia. The fresh rhizomes serve as a healing agent for cuts or boils. In Assam, it is believed that the presence of turmeric plants on pond banks deters predators like snakes and otters from entering the pond. Beyond its medicinal uses, turmeric is a crucial food ingredient, making it advantageous for farmers to cultivate on pond dykes (Bhuyan and Neog., 2018). Tapioca, locally known as simolu aalu, is a valuable source of starch (90%) and serves as a staple food in many regions. Ideally suited for cultivation on pond dykes, tapioca requires dry and alluvial soil. With year-round growth and abundant root production, tapioca plantations on new pond dykes help minimize soil erosion without negatively impacting pond water. Utilizing the typically idle pond embankment proves beneficial for tapioca cultivation (Bhuyan and Neog., 2018).

Gourd cultivation requires ample space, sufficient light, and water. These flowering plants feature spreading vines, colourful flowers, lobed leaves, and long twisting tendrils. Pond dykes, being in well-lit areas, are ideal for gourd farming. Additionally, the space over the water body can be utilized for gourd cultivation using bamboo hanging fencing. During the dry season, water from the pond is used to irrigate the gourd plants. Gourds, being in high demand locally, enjoy a robust market (Bhuyan and Neog., 2018). Lemon trees are typically planted along the outer boundaries of the pond, serving as border fencing. Planting materials are planted on pond embankments during the monsoon season, with pits of 0.5 m x 0.5 m size spaced at 3m x 3m. After the second year, the lemon plants begin bearing fruit continuously throughout the year, with the peak period from July to September. Harvesting is recommended when the fruits reach full maturity. To ensure good lemon production, an ample supply of organic manure is essential, with pond silt serving as excellent manure. Beyond fruit production, lemon trees act as effective bio-fencing around the pond (Bhuyan and Neog., 2018).

MULTI-TIER APPROACH IN DEEP-WATER AREAS COMBINING RICE CULTIVATION, FISH FARMING, AND HORTICULTURE:

Deep-water rice ecosystems offer opportunities for diversified farming, incorporating elements such as horticulture, aquaculture, livestock, agroforestry, and more. Implementing a farming system based on rice, fish, and horticulture ensures increased productivity, income, employment, and environmental security. The multi-tier approach involves designing fields, shaping land, and implementing specific practices for each component.

Site selection:

Choose semi-deep to deep water rice fields with water depths ranging from 50-100 cm (maximum 150 cm), ensuring they are free from recurrent flash floods.

- Prefer farms with clay soil for enhanced water retention capacity.
- Opt for farms of one acre to one hectare or more in size.
- Preferably select farms with rectangular or square shapes.

Field Design and Construction:

The farm adopts a multitier system, comprising an upland (Tier I – fruit and vegetable crops and Tier II – tuber and vegetable crops) covering 15% of the area. The rice field makes up 40%, divided into rainfed lowland (up to 50cm water depth, Tier III) and deep water (50-100cm water depth, Tier IV). The upland is further divided for short-term and long-term fruit crops (Tier I) and tuber crops and year-round vegetable production (Tier II). A gentle gradient of 0.5% is maintained across Tiers I and II, while a 1% gradient exists across rainfed lowland (Tier III) and deepwater (Tier IV) rice fields. Two ponds (micro-watersheds) covering 25% of the area are constructed, serving as fish and prawn refuge and for fish fingerlings' and yearlings' production (Sinhababu et al., 2012).

Rainwater collected in the ponds is utilized for irrigation in various tiers. Raised bunds surround the area, utilizing 20% of the farm, with a 1:1 side slope in heavy soil. The bunds are 1.5 m high and 2 m wide, positioned 50 cm higher than the maximum water level, and a 1 m 'berm' between ponds and bunds minimizes soil erosion. Duck and poultry houses are erected on the pond refuge bund, extending over the pond water to utilize droppings as manure and fish food. Low-cost duckery and poultry units can be fashioned from bamboo or wire net with straw thatching or asbestos top. The estimated construction cost for one hectare of farm area is approximately 1,30,000, and for duck and poultry houses, it is 20,000. The dimensions of tiers, ponds, and bunds can be adjusted based on agro-climatic conditions, hydrology, and farmer requirements (Sinhababu et al., 2012).

ACHIEVEMENTS OF INTEGRATED FISH FARMING:

The recent focus on integrating livestock and horticulture with aquaculture highlights the use of animal manures for fish pond fertilization (Delmendo, 1980). Combining fish, poultry, and various horticultural crops, including Bombe red onion, Malkashola Tomato, and Cabbage, has demonstrated higher production in integrated systems compared to non-integrated ones (Hirpo, 2017). Karim et al. (2011) provide convincing evidence that commercialization of fish and vegetable production can be achieved while maintaining their complementary nature, particularly with intensified aquaculture utilizing enhanced nutrient inputs. The Integrated Farming System (IFS) inherently promotes self-employment by offering numerous job opportunities and enhancing farmers' livelihoods. Sharma et al. (2016) underscore the effectiveness of integrated pond management, which incorporates fish, poultry, and horticulture, as a commendable strategy for achieving sustainable production, generating income, and providing employment opportunities for economically disadvantaged rural households.

Yadav et al. (2013) found that enhanced fruit production was linked to improved nutrient availability during critical growth phases, facilitated by nutrient-rich pond water utilized for irrigation. This led to increased synthesis of carbohydrates and their transportation to storage organs. Hailu et al. (2023) conducted a Pre-extension Demonstration of Fish-Poultry-Horticulture Integration Farming System, advocating its significant role in sustainable development for addressing food insecurity at both regional and national levels. Temperature impacts the yield and production of eggs and fish in integrated farms, emphasizing the need for effective technical advice delivery to support farmers in managing the system and enhancing productivity. For optimal results, large fish ponds with areas above 100 m^2 and depths of 1.50m, especially in highland areas above 2000 m.s.l., are recommended to maintain water temperature and provide ample space for photosynthesis, ensuring sufficient natural feed production in ponds.

Chakrabarti and Banerjee (2021) unveiled that vegetables and fruit trees grown on pond embankments provide additional income to farmers' families. The pivotal role of fisherwomen in fish, livestock, and vegetable production holds paramount importance for family nutrition. According to ICAR norms, more than two-thirds of the population in rural households in India are undernourished (Chand and Jumrani, 2013). Abera (2021) conducted horticulture activities a week after stocking fish and poultry to enhance nutrient levels in the pond for integrated horticulture production. Horticultural species included Potato (Solanum tuberosum), Gurage cabbage, and Ball-head cabbage (Brassica oleraceavar. capitata). Mesfin (2021) demonstrated a yield difference between vegetables and herbs irrigated with fish pond water and non-irrigated plots, both through physical biomass observation on the ground and harvest measurements. The observation revealed that beetroot irrigated with fish pond water exhibited markedly greater above-ground leaf biomass compared to non-irrigated beetroot. This discovery challenges the conventional scientific belief that fish pond water generally enhances overall yield by promoting growth of both consumable and vegetative crop parts through additional fertilization with pond water effluent.

CONCLUSION:

The association of fish-poultry-horticulture yields substantial returns. Economic analysis comparing the production costs of poultry birds, fish, and papaya with their farm-gate sale prices indicates significantly higher profits for farmers. Integration requires minimal investment but results in much higher income compared to non-integrated farming. With land being a limited resource, integrated farming provides a viable solution to produce more food from existing agricultural land. The integrated farming system is likely to play a crucial role in boosting production, ensuring remunerative returns, meeting nutritional requirements, creating employment opportunities for rural populations, and contributing to the national economy.

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