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Integrated Approaches in Sericulture: Resource Efficiency, Livelihood Security, and Environmental Conservation

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Integrated Farming Systems (IFS) represent a holistic agricultural approach that combines multiple enterprises within a single farm unit to optimize the use of resources, ensure sustainability, and enhance economic returns. Within the framework of sericulture, IFS models have gained significant attention due to their ability to interlink silk production with complementary sectors such as crop cultivation, livestock rearing, horticulture, agroforestry, poultry farming, pisciculture and apiculture. These interconnections foster symbiotic relationships among different components, facilitating efficient utilization of farm outputs and by-products through waste recycling, nutrient cycling, and value addition. The integration of sericulture with allied activities not only diversifies farmers' income sources but also improves soil fertility, boosts crop productivity, and reduces dependency on external inputs. Furthermore, such systems strengthen rural livelihoods by generating year-round employment.

Introduction

Sericulture, an agro-based industry with both agricultural and industrial components, plays a vital role in the rural economy of India. The cultivation of mulberry (*Morus* spp.) and the rearing of the silkworm (*Bombyx mori* L.) are primarily agricultural activities, whereas post-cocoon operations such as reeling, twisting, and weaving fall under the industrial sector. India is currently the second-largest producer of mulberry silk in the world, after China, with an annual production of 38,913 metric tonnes during 2023–24. The industry directly and indirectly provides livelihood opportunities to nearly 8.8 million people, most of whom belong to rural and semi-urban areas.

Over the years, sericulture has emerged as a powerful tool for inclusive rural development, particularly benefiting marginalized groups such as women, tribal communities, and economically weaker sections. It has facilitated a more equitable distribution of resources and opportunities, bridging the gap between urban and rural populations. With its eco-friendly production process, high employment potential, low initial investment requirements, and quick returns, sericulture has established itself as a sustainable and remunerative livelihood option. In addition, its integration with biotechnology and other modern agricultural practices has further enhanced its potential for innovation and value addition.

Mulberry, the sole food plant for silkworms, also holds significant ecological and economic value. As a perennial, deep-rooted, and highly adaptable plant, it can thrive under diverse agro-climatic conditions. It is a fast-growing species capable of producing abundant foliage rich in proteins, which serves not only as nutritious feed for silkworms but also as fodder for livestock. Although naturally a medium-sized tree, mulberry is often managed as a bush in intensive cultivation systems to suit the requirements of sericulture. Furthermore, it can be cultivated both as a monocrop and in combination with agricultural and horticultural

crops, thereby maximizing land-use efficiency, particularly in sub-tropical regions where sericulture is often practiced as a subsidiary occupation.

Beyond its direct role in sericulture, mulberry also contributes significantly to environmental conservation and rural resource management. Its high biomass production and multipurpose utility make it an effective tool for addressing challenges such as fuelwood scarcity, fodder shortages, timber needs, rural unemployment, and environmental degradation. Moreover, mulberry plantations play a role in soil conservation, improvement of wastelands, and promotion of cottage industries. Thus, the plant holds promise not only for sustaining silk production but also for enhancing ecological resilience and supporting diverse livelihood opportunities (Rama et al., 2004).

Integrated Farming Models in Sericulture

1. Seri-Livestock Integration

Sericulture and animal husbandry are two complementary agricultural practices that can be successfully combined to create a sustainable and resilient farming system. This integration not only enhances resource utilization but also diversifies income sources, providing farmers with greater economic stability.

Mulberry (*Morus* spp.), the primary food plant of silkworms, has long been recognized for its high nutritional value as animal fodder. Its leaves are rich in protein, minerals, and digestible fibers, making them highly palatable to ruminants. Research indicates that incorporating mulberry leaves into the diet of dairy cows can significantly improve their nutritional status and milk yield (Sanchez, 2000).

The rearing process in sericulture also generates substantial organic waste, such as bed refuse, which can be effectively utilized in animal husbandry. For instance, waste from a mulberry plantation can support the maintenance of 10–12 sheep or goats per hectare. Studies have shown that the debris generated from the rearing of 1000 disease-free layings (DFLs) in a chawki rearing center is sufficient to sustain 4–5 sheep or goats. This practice transforms sericultural by-products into valuable livestock feed, thereby reducing wastage and increasing farm efficiency.

The phrase *"silk and milk go hand in hand"* reflects the synergy between sericulture and dairy farming. In many sericulture-intensive regions, farmers routinely use rearing waste and leftover mulberry foliage as feed for cattle, particularly during the dry season when conventional fodder resources become scarce. This ensures the survival and productivity of livestock while simultaneously lowering feeding costs.

Animal husbandry also contributes positively to sericulture. Sheep and goat manure provides an excellent source of organic fertilizer for mulberry gardens, improving soil fertility and plant growth. On average, a herd of 15 sheep or goats can produce about one ton of manure every three months when maintained under stall-feeding systems. Furthermore, when livestock are allowed to graze in mulberry plantations after shoot harvest, they not only fertilize the soil naturally but also assist in pruning the plants, thereby reducing the need for manual labour.

Studies by Nagaraju and Raghavendra (2016) demonstrated that integrated farming systems combining sericulture, crop cultivation, and livestock (particularly dairy, sheep, and goat rearing) provided substantial economic and employment benefits. The system generated an estimated 322 man-days of employment annually, indicating its strong potential for rural livelihood security. Additionally, the practice of using mulberry as fodder during market downturns in the silk sector helps mitigate risks for entrepreneurs and ensures farm sustainability.

Thus, the Seri–Livestock Integrated Farming System exemplifies a sustainable approach to agriculture where resources are used efficiently, wastes are recycled, and farmers gain economic resilience. The interdependence between mulberry cultivation, silkworm rearing, and livestock farming not only supports multiple income streams but also strengthens soil fertility, reduces environmental degradation, and enhances food and livelihood security in rural communities.

2. Seri-Horticulture Integration

The integration of sericulture with horticulture offers a sustainable model of land use that enhances resource efficiency, diversifies farm outputs, and provides farmers with multiple sources of income. Since mulberry, the primary host plant of silkworms, is adaptable to various cultivation systems, it can be easily incorporated into mixed-cropping and horticultural landscapes without requiring farmers to dedicate their entire land exclusively to sericulture.

One of the most common approaches is the cultivation of mulberry as tall trees along the borders of vegetable fields or interspersed within horticultural orchards. Studies have shown that perennial fruit crops such as mango (*Mangifera indica*), coconut (*Cocos nucifera*), and sapota (*Manilkara zapota*) can be successfully integrated with mulberry plantations, thereby maximizing land-use efficiency while generating additional income for farmers (Kerutagi et al., 2019). This system is particularly advantageous for smallholder farmers, as it allows them to practice sericulture on a part-time basis while deriving income from horticultural produce.

Floriculture represents another promising avenue within the Seri–Horti Integrated Farming System. Establishing small-scale nurseries or cultivating flowers on limited plots requires relatively little time and investment yet provides high economic returns. Importantly, sericultural by-products such as silkworm litter and rearing waste can be composted into biofertilizers, which in turn promote the growth of floricultural crops (Baishya et al., 2004). A wide range of flowers—including gladiolus, marigold, China aster, chrysanthemum, rose, crossandra, and tuberose—can be cultivated alongside mulberry. Interestingly, marigold (*Tagetes spp.*) provides additional agronomic benefits by suppressing root-knot nematodes, which are common pests in mulberry plantations (Wang et al., 2007). Thus, the integration of floriculture not only diversifies income but also improves mulberry health and productivity.

Intercropping mulberry with region-specific cash crops further enhances the adaptability of this system. For example, in saffron-growing areas, intercropping mulberry with saffron (*Crocus sativus*) has been reported to produce high-quality mulberry leaves while simultaneously offering farmers additional revenue during the offseason when saffron-related activities are minimal (Kaur et al., 2002). Likewise, medicinal plants such as *Aloe barbadense* (aloe vera), *Asparagus racemosus* (shatavari), and *Acorus calamus* (sweet flag) have been found compatible with mulberry cultivation, opening opportunities for farmers to tap into the growing herbal and pharmaceutical markets (Madhusudan et al., 2015).

Further evidence highlights the success of intercropping mulberry with short-duration crops such as garlic, onion, carrot, and turmeric. Studies by Singhvi and Katiyar (2009) and Khan et al. (2015) revealed that such intercropping systems not only increased cocoon production through improved soil fertility and mulberry leaf yield but also provided additional profits from the sale of intercrops. These findings demonstrate that integrating horticultural crops with sericulture enables a balanced and diversified farming system that enhances resilience to market fluctuations.

Overall, the Seri–Horti Integrated Farming System embodies the principles of sustainable agriculture by ensuring efficient land utilization, recycling sericulture wastes into bio-inputs, and creating multiple income avenues for farmers. This integration not only strengthens farm-level economies but also contributes to soil health, pest management, and long-term sustainability of sericulture-based livelihoods.

3. Seri-Agriculture Integration

The integration of sericulture with agriculture provides farmers with a sustainable and profitable farming model that ensures optimal utilization of land, soil fertility management, and multiple sources of income. Since mulberry (*Morus spp.*) is the sole food source for the silkworm (*Bombyx mori L.*), its quality and yield directly influence cocoon production, contributing nearly 38.2% to the success of silk output. Integrating mulberry with suitable agricultural crops not only enhances leaf yield and quality but also generates additional food and fodder for farm families, thereby strengthening livelihood security.

One of the most effective strategies in the Seri–Agri Integrated Farming System is intercropping mulberry with pulses. Pulses such as green gram, black gram, horse gram, and cowpea are nitrogen-fixing crops that enrich soil fertility while reducing the dependency on synthetic fertilizers. Studies have demonstrated that intercropping mulberry with pulses improves mulberry leaf yield, boosts grain and fodder production, and enhances soil organic matter through crop residue recycling (Qadri et al., 2004; Babu and Dandin, 2009; Rajegowda et al., 2020). This practice also ensures that the nutritional requirements of mulberry plants are met in an eco-friendly manner, thereby producing high-quality leaves for silkworm rearing.

Economic analyses further highlight the advantages of Seri–Agri integration. Intercropping mulberry with field beans, finger millet has been shown to yield higher benefit–cost ratios compared to monocropped mulberry systems (Shashidhar et al., 2022). Among different combinations, mulberry–cowpea intercropping proved especially profitable, owing to enhanced soil fertility, improved mulberry leaf production, and higher cocoon yields, resulting in greater overall income for farmers (Rajegowda et al., 2020). Experimental results also indicate that mulberry intercropped with cowpea at a spacing of 90 × 90 cm during the monsoon season (June–August) produced the maximum intercrop yield and net profit per hectare (Mishra et al., 2009).

Beyond immediate economic gains, the Seri–Agri model contributes significantly to long-term soil health and sustainability. By integrating legumes and short-duration crops into mulberry plantations, the system maintains soil structure, replenishes nutrients, and reduces the need for external chemical inputs. Additionally, intercrops provide dietary diversity and food security for rural households, thereby strengthening resilience against market or climatic fluctuations.

The Seri–Agri Integrated Farming System enhances productivity, profitability, and sustainability by combining mulberry cultivation with compatible agricultural crops. It supports high-quality cocoon production while simultaneously generating additional farm outputs such as grains, fodder, and organic matter. This holistic approach not only improves farmer incomes but also conserves natural resources, making it an essential component of modern sustainable farming practices.

4. Seri-Forestry Integration

Agroforestry, which combines forestry with agricultural practices, has long been recognized as a sustainable land-use system that promotes ecological balance, resource recycling, and multiple economic returns. When integrated with sericulture, it forms the Seri–Forest Integrated Farming System, which not only supports silk production but also contributes to climate resilience, fodder availability, and environmental conservation.

Sericulture-based agroforestry systems (AFS) have demonstrated high potential for profitability and sustainability (Dhyani et al., 1996). In such systems, mulberry trees are cultivated alongside or within forest plantations, linking sericulture with silviculture. The remunerative nature of this approach motivates farmers to adopt mulberry plantations while simultaneously enhancing ecosystem services. Mulberry, being a high-biomass-producing tree species, plays a crucial role in climate change mitigation by sequestering substantial amounts of atmospheric carbon dioxide. Moreover, mulberry leaves decompose quickly after shedding, ensuring rapid recycling of nutrients and carbon back into the soil, thus improving soil fertility and supporting sustainable crop production (Kumar et al., 2019).

The integration of mulberry into silvi-pastoral systems has proven particularly advantageous. For example, *Morus*-based silvi-pastoral models can yield approximately 8,000 kg/ha of green tree fodder and 24,000 kg/ha of green grass fodder annually (MoAC&FW, 2021). This dual production system enables farmers to obtain three harvests of nutritious tree fodder while also ensuring the availability of quality green grass during lean periods, thereby strengthening livestock management. The use of mulberry in silvi-pastoral systems thus enhances the productivity of both animal husbandry and sericulture, creating a well-rounded integrated farming model.

Another noteworthy advantage of mulberry plantations in forestry systems is their role in mitigating human–wildlife conflicts. Unlike many other agricultural crops, mulberry foliage is not consumed or damaged by elephants (Kumara and Yogendra, 2022). Therefore, mulberry-based agroforestry can serve as a strategic land-use option in regions prone to elephant incursions, reducing crop losses and improving farmer security.

Mulberry is also well-suited as an intercrop in commercial timber plantations such as silver oak (*Grevillea robusta*), teak (*Tectona grandis*), and Malabar neem (*Melia dubia*). Intercropping mulberry with these forestry species allows farmers to earn regular income from silkworm rearing while waiting for long-rotation timber trees to mature. This dual-income system enhances economic resilience and encourages the adoption of sustainable forestry practices.

In summary, the Seri–Forest Integrated Farming System combines the ecological benefits of forestry with the economic and employment potential of sericulture. It ensures sustainable carbon cycling, supports fodder production, reduces wildlife conflicts, and diversifies farmer income. By aligning environmental conservation with rural livelihoods, this integration serves as a model of climate-smart and socially beneficial farming.

5. Seri-Poultry Integration

Poultry farming is one of the most dynamic and profitable livestock sectors, but it is also heavily dependent on feed resources, which account for nearly 65–70% of the total production cost. Among feed components, animal protein contributes significantly—making up nearly 15% of the overall expenditure—and is often the costliest ingredient in poultry nutrition. This dependency creates an opportunity for sericulture by-products to be utilized as sustainable feed alternatives, thereby reducing input costs and enhancing farm profitability.

Silkworm pupae, a major by-product of the silk-reeling industry, are particularly rich in proteins, lipids, and essential vitamins and minerals. Studies have shown that incorporating silkworm pupae into poultry diets provides a high-quality protein supplement capable of replacing more expensive animal protein sources (Longvah et al., 2011). Similarly, silkworm larvae and pupae, when mixed with appropriate feed ingredients, produce balanced poultry rations that support growth, egg production, and overall health. This not only reduces feed costs but also adds value to sericulture waste, making the integration of sericulture and poultry a promising model for smallholder farmers as well as commercial enterprises (Prein, 2002).

The benefits of integration extend beyond feed utilization. Poultry rearing generates considerable amounts of waste, which can be recycled into organic manure. This poultry manure, rich in nitrogen and other nutrients, serves as an effective biofertilizer for mulberry gardens (Kumar et al., 2012). Application of this manure enhances soil fertility, improves mulberry growth, and ensures the production of nutrient-rich leaves for silkworm feeding. Consequently, healthier silkworms spin superior quality cocoons, creating a positive cycle of productivity between poultry farming and sericulture.

In addition to manure management, the practice of raising poultry—particularly domestic fowl and guinea fowl—within mulberry gardens has shown multiple ecological and economic benefits. These birds contribute to natural weeding, pest control, and fertilization, thereby reducing the need for chemical inputs. Studies have reported that poultry raised under such systems showed improvements in egg quality, including a higher Haugh unit (a measure of egg freshness and albumen quality). Furthermore, the inclusion of mulberry leaves in poultry diets has been found to increase the vitamin K1 content of eggs and reduce the odour of manure, making poultry farming more environmentally friendly (Machii, 2000).

Thus, the Seri–Poultry Integrated Farming System exemplifies a mutually beneficial relationship: sericulture provides high-quality feed ingredients for poultry, while poultry farming contributes manure and ecosystem services that enhance mulberry cultivation. This circular system reduces waste, improves farm-level sustainability, and increases income opportunities. By creating synergies between sericulture and poultry, farmers can achieve

higher economic returns, diversify their livelihoods, and promote environmentally sustainable agriculture.

6. Seri-Pisciculture Integration

The integration of sericulture with pisciculture (fish farming) is a unique and resource-efficient model of the Integrated Farming System (IFS) that exemplifies circular bio economy principles. This approach harmoniously combines mulberry cultivation, silkworm rearing, silk extraction, and fish farming into a mutually supportive system. Each component plays a distinct role: mulberry serves as the primary producer of foliage, silkworms act as the primary consumers by feeding on mulberry leaves, and fish become the secondary consumers by utilizing sericulture by-products such as silkworm pupae and faeces.

Scientific studies highlight the potential of this integrated approach for improving fish productivity. Research by Kumar et al. (2012) demonstrated that silkworm by-products—including faeces, waste pupae, and rearing wastewater—can be effectively used in fish farming. For instance, trout fish fed with silkworm pupae meal achieved marketable weights of approximately 250 g/fish within 8–9 months, compared to 12–13 months under traditional feed regimes. Importantly, this accelerated growth was achieved without compromising fish health or survivability, indicating the high nutritional value and digestibility of silkworm-derived feed.

The integration of sericulture and aquaculture has deep cultural and historical roots, particularly in China, where it has been extensively practiced and documented (Ruddle and Zhong, 1989; Zhong, 1995). In these traditional systems, waste products from silkworm rearing—such as pupae, droppings, and tray washings—are recycled into fishponds, enriching the aquatic environment. These inputs increase the organic matter and nutrient content of pond sediments, which in turn improve plankton production and overall pond fertility. The nutrient-rich pond mud (humus) can subsequently be applied to mulberry fields as organic manure, completing a sustainable nutrient cycle.

Beyond nutrient recycling, the Seri–Pisci system offers several additional benefits. First, it diversifies farmer income, providing both silk and fish products from the same land-use framework. Second, it improves food security by supplementing household diets with fish protein. Third, it promotes environmental sustainability by reducing waste, minimizing reliance on external feed and fertilizers, and enhancing soil–water interactions.

Overall, the Seri–Pisci Integrated Farming System exemplifies the principles of ecological balance and resource optimization. By effectively utilizing sericulture by-products in fish farming and recycling pond outputs back into mulberry cultivation, this model creates a closed-loop system that enhances productivity, reduces costs, and promotes environmental conservation. For smallholder farmers, it represents a promising pathway toward diversified income generation and long-term sustainability.

7. Seri-Apiculture Integration

The integration of sericulture with apiculture (bee-keeping) forms another promising model of resource-efficient farming. Mulberry trees, along with associated intercrops, provide abundant floral resources in the form of nectar and pollen, which are essential for sustaining honeybee colonies. This relationship creates a win–win situation: while sericulture benefits from mulberry leaf production for silkworm rearing, apiculture thrives on the floral resources of mulberry and other associated crops, leading to enhanced farm productivity and income diversification.

Mulberry flowers, as well as those from non-mulberry sericulture host plants, are known to be rich sources of pollen (Rijal et al., 2018). The flowering period of mulberry coincides with critical foraging periods for honeybees, providing a reliable and consistent pollen supply. Furthermore, intercropping mulberry with pulses, fruits, oilseeds, vegetables, and ornamental plants not only improves land-use efficiency but also broadens the pollen and nectar base for bees. This diversified floral availability supports colony health, improves honey yield, and enhances pollination services for the intercrops.

Apiculture in mulberry-based farming systems offers multiple socio-economic and ecological advantages. From a farmer's perspective, it provides a subsidiary income source through the sale of honey, beeswax, pollen, royal jelly, and propolis. These products command high demand in both domestic and export markets due to their nutritional and medicinal value. The adoption of beekeeping alongside sericulture thus contributes significantly to income resilience, reducing the risks associated with dependence on a single crop or product.

Ecologically, the presence of honeybees enhances pollination efficiency in mulberry orchards and intercrops, leading to improved yields of fruits, vegetables, and pulses. This ecological service strengthens the sustainability of integrated farming by improving biodiversity and maintaining ecosystem balance. Moreover, apiculture is a low-input activity that can be easily managed by smallholders and women farmers, making it socially inclusive and a viable tool for rural employment generation.

Studies have demonstrated that mulberry plantations intercropped with legumes, oilseeds, and fruit-bearing plants can significantly increase honey production while simultaneously enriching soil fertility and improving silkworm nutrition. This integrated model has been widely adopted in several Asian countries, particularly India, China, and Nepal, where sericulture and apiculture coexist as complementary activities within rural livelihood systems.

In conclusion, the Seri–Apiculture Integrated Farming System exemplifies how sericulture can be harmonized with apiculture to enhance farm productivity, promote biodiversity, and diversify income sources. By leveraging the floral resources of mulberry and associated intercrops, farmers can benefit from both silk and honey production, thereby strengthening rural economies and promoting sustainable agricultural practices.

Conclusion

Integrated Farming Systems (IFS) in sericulture provide a sustainable pathway to maximize resource efficiency, diversify income sources, and strengthen rural livelihoods. The combination of mulberry cultivation and silkworm rearing with allied enterprises such as livestock, horticulture, agriculture, forestry, poultry, pisciculture, and apiculture creates a circular and mutually supportive system. This integration ensures efficient recycling of wastes, enhances soil fertility, reduces dependence on chemical inputs, and promotes biodiversity conservation.

Economically, sericulture-based IFS models offer farmers multiple revenue streams, reduce risks associated with market fluctuations, and generate year-round employment. Ecologically, they contribute to carbon sequestration, soil and water conservation, and climate resilience. Socially, these systems empower women, smallholders, and marginalized communities by providing accessible and remunerative livelihood opportunities.

Thus, sericulture, when practiced as part of an integrated farming system, is not limited to silk production alone but emerges as a catalyst for sustainable agriculture, rural development, and environmental protection. By blending traditional practices with modern innovations, Seri-based IFS models hold immense promise as a future-ready approach to resilient farming and inclusive growth.

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