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Advancing sustainability in agriculture: A review of integrated farming systems for improved farm resilience and ecosystem health

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Abstract

This review article examines Integrated Farming Systems (IFS) as a comprehensive approach to advancing sustainability in agriculture. IFS, which integrates crops, livestock, fishery, and allied activities within a single farm, is proposed as a strategy to enhance farm resilience, livelihoods, food security, and ecosystem health. The review of existing literature highlights that IFS can significantly boost farm profitability by 265% and employment by 143% compared to single-enterprise farms. IFS contribute to sustainability by enhancing nutrient recycling, reducing reliance on external inputs, and improving soil quality indicators. The integration of diverse agricultural activities promotes efficient use of resources, minimizes waste, and supports soil health through organic matter and nutrient cycling. Additionally, IFS foster biodiversity conservation, increase soil organic carbon, and help mitigate greenhouse gas emissions. However, challenges such as the need for specialized skills, resources, and capital among small and marginal farmers hinder widespread adoption. The study underscores the necessity of integrating productivity, profitability, and environmental sustainability within a unified evaluation framework to enhance the adaptability and effectiveness of IFS. Overall, IFS emerges as a robust and climate-resilient model for sustainable agriculture, highlighting the need for continued research, policy support, and innovative strategies for its broader implementation.

Keywords: Integrated farming systems, farm resilience, ecosystem health, nutrient recycling

Introduction

Sustainable food systems are designed to meet current food demands without compromising the ability of future generations to do the same. According to the FAO, such systems are socially, economically, and ecologically sustainable, focusing on food security and nutrition while preserving the economic, social, and environmental bases that support them. This involves ensuring food safety and nutrition across the entire supply chain, from production to consumption, making food accessible to all. The goal is to improve the quality of life by promoting profitable production, protecting resources, efficiently using both nonrenewable and on-farm resources, and minimizing total energy consumption.

Sustainable Food Systems - A Balanced Approach

While modern industrial agriculture has boosted yields and food availability, it has also contributed significantly to environmental degradation. Agriculture is a major source of greenhouse gas emissions, including carbon dioxide, methane, and nitrous oxide. It also leads to issues like soil acidification, eutrophication, nutrient runoff, fertilizer residue accumulation, and water pollution from inefficient irrigation. These practices have resulted in soil degradation, biodiversity loss, habitat destruction, and a reduction in the resilience of agricultural landscapes, ultimately impacting human health, farm incomes, and the environment.

Worldwide necessity for environmentally sustainable farming practices

To meet the nutritional needs of a projected 9–10 billion people by 2050, crop production must increase by 60–100% while reducing environmental impact. The Green Revolution's reliance on fertilizers, pesticides, and irrigation secured food for billions but at a significant environmental cost. In the 21st century, soil and water conservation will be crucial for food security, and sustainable precision agriculture and environment (SPAE) practices are needed to mitigate the impact of intensive agriculture and climate change. Next-generation cropping systems should combine biologically-based technologies, such as plant-beneficial microbes and cover crops, with precision agriculture (PA) and precision conservation (PC) to reduce inputs and enhance conservation. Developing crop cultivars with improved nutritional content and resilience to abiotic and biotic stresses through advanced breeding and biotechnology is also essential. PA, PC, and sustainable agriculture are interconnected, focusing on increasing conservation effectiveness and sustainability (Pierce and Nowak, 1999 and Delgado and Berry, 2008) [12, 1]. The 21st century presents significant sustainability challenges, particularly the need to increase agricultural production in the face of climate change. The United Nations has warned that climate change is accelerating faster than humanity's response, leading to more extreme weather and increased erosion risks in agricultural systems (Pruski and Nearing, 2002) [13]. Conservation practices are vital for maintaining agricultural productivity and sustainability in a changing climate (Delgado *et al.*, 2011) [2]. Additionally, big data analysis will play a key role in developing sustainable systems.

Key Objectives

1. **Explore and Assess IFS:** Investigate how Integrated Farming Systems (IFS) can meet agricultural demands, ensuring environmental sustainability while delivering significant economic benefits, including enhanced farm profitability and employment compared to single enterprise farms.
2. **Investigate Environmental and Climate Impact:** Examine the environmental benefits of IFS, such as nutrient recycling, soil quality enhancement, biodiversity conservation, and greenhouse gas emissions reduction, highlighting its role as a climate-resilient model for sustainable agriculture.
3. **Address Challenges and Propose Strategies:** Identify the challenges in IFS adoption, particularly for small and marginal farmers, and propose future research, policy support, and innovative strategies to facilitate widespread IFS adoption.

Integrated Farming Systems (IFS): Key Insights and Sustainability Impact

Integrated Farming Systems (IFS) began in 1978 in Lautenbach, Germany, as a response to environmental concerns associated with conventional farming. This approach integrates crop cultivation, livestock management, and fisheries into a holistic, low-input farming method that contrasts with traditional agriculture. IFS operates on the principle that "there is no waste," transforming by-products into valuable inputs across various enterprises (Morris and Winter, 1999) [10]. IFS enhances farm profitability by recycling waste, reducing reliance on external inputs, and boosting productivity, particularly in arid and semi-arid regions (Ravisankar *et al.*, 2007) [15]. It supports sustainable agriculture by improving soil fertility through the use of livestock manure and reducing dependence on chemical fertilizers (Gupta *et al.*, 2012) [6]. Additionally, IFS provides continuous income streams from diverse farm products like eggs, milk, and honey, reducing financial risks for farmers and promoting year-round economic stability (Devendra, 2002) [3]. As a resource management strategy, IFS fosters economic and sustainable production, conserves natural resources, and mitigates the impact of climate change on crop yields (Gangwar *et al.*, 2013) [5]. It offers a viable micro-business model for farm youth, ensuring regular income and reducing the risk of single-crop failures (Khan *et al.*, 2012) [9].

Adoption strategies to climate change

The IFS farmers of the four ACZs adopted several measures to counter the changing climate in different components of the IFS. Only 17% of the IFS farmers in the arid region adopted insurance to reduce crop failure and livestock health risks. While the IFS farmers of semi-arid, sub-humid, and humid regions were found to be more aware of crop insurance to reduce the associated risk of crop failure. Almost all the IFS farmers in all the ACZs practice change in planting dates, majorly to avoid terminal drought/rainfall, pest and disease incidence, and a contingency plan to prevent short/extended mid-season dry spells. Intercropping is one of the best low-cost climate-resilient practices, adopted majorly to reduce soil erosion, improve soil fertility (by including legumes as a cover crop), and as a trap crop to break the pest and disease cycle. The adoption of intercropping was found higher in arid and semi-arid zones. Higher adoption under arid and semi-arid zones is mainly due to higher water constraints and shorter growing periods because of poor rainfall distribution. The earlier studies also reported that intercropping as a climate-resilient strategy is more in arid and semi-arid zones to avert economic loss. Adopting a mixed cropping/intercropping system also provides food and nutritional security to the farm household and exploits the interspace between the main crop and extra moisture. Likewise, most IFS farmers across the ACZs have changed to short and drought-resistant varieties as a contingency plan for terminal drought/dry spells. These varieties were high-yielding and completed their lifecycle 30–40 days earlier than the traditional varieties and provided a scope for the sequential crop after the main crop. The farmers of semi-arid, sub-humid, and humid zones were essentially adopting soil and moisture conservation techniques to control runoff and water erosion. The rainwater harvest mechanism is used at Gladstone village in Central South Africa to mitigate drought stress (Gandure *et al.*, 2013) [4]. Farmers were conserving water by practicing farm ponds to avail of the same in the summer season. The adoption of compartmental bunding, contour bunds, and live bunds was most effective in reducing soil and nutrient loss under slopy areas. The establishment of field bunds plays a critical role in choking floods and increasing water infiltration into the soil.

Findings on Integrated Farming Systems (IFS) for Sustainable Development

1. **Enhanced Food Production through IFS:** IFS models have demonstrated remarkable potential in increasing food production, particularly among small and marginal farmers, who benefit from reduced reliance on external inputs and increased resilience against climate variability. Studies conducted in northwest India revealed that IFS models significantly outperformed the traditional rice-wheat system (M1). The food production in these models was approximately 2 to 6 times higher than in conventional systems. Notably, the model combining crop cultivation with dairy, fishery, poultry, duckery, apiary, boundary plantation, biogas units, and vermicomposting (M10)

exhibited the highest food production rate at 61.5 Mg ha^{-1}, surpassing other integrated models such as M9 (60.0 Mg ha^{-1}), M7 (59.5 Mg ha^{-1}), and M6 (58.2 Mg ha^{-1}). These findings underscore the potential of IFS to substantially increase food production while enhancing the resilience of farming systems to environmental challenges (Dasgupta, 2021) [14].

2. **Employment Generation through IFS:** IFS offers a viable strategy for employment generation by creating continuous labor demand for the management of diverse agricultural enterprises. This approach is particularly relevant during periods of economic uncertainty, such as the COVID-19 pandemic, where it provided alternative employment opportunities for reverse migrants moving from urban to rural areas. The integration of various agricultural components within IFS models ensures year-round engagement of farm families, thereby contributing to sustained employment and income generation. Research findings indicate that IFS models, such as pig-based systems and crop-fish-duck integrations, significantly enhance employment, income, and overall livelihoods compared to monocropping systems. Moreover, these models have been shown to offer higher economic returns, improved water productivity, and increased energy output, presenting a promising and financially rewarding alternative to traditional cropping systems.
3. **Soil Health and Residue Recycling in IFS:** IFS plays a crucial role in promoting soil health and sustainability through the effective recycling of organic residues and the integration of locally available inputs with minimal reliance on external resources. This approach addresses the environmental degradation often associated with the excessive use of fertilizers and pesticides in conventional farming systems. By incorporating crop residues, livestock manure, and other organic inputs, IFS enhances nutrient use efficiency, promotes nutrient recycling, and increases soil microbial activity. Empirical studies have documented significant improvements in soil health metrics, such as nutrient availability and soil fertility, through the adoption of IFS practices. These findings highlight the potential of IFS as a resource management strategy that not only conserves soil health but also contributes to environmental conservation by optimizing the use of available resources (Paramesh *et al.*, 2022) [11].
4. **Climate Impact of IFS:** The impact of IFS on climate change mitigation is evident in the observed variations in global warming potential (GWP), greenhouse gas intensity (GHGI), and eco-efficiency index (EEI) across different IFS models. While the integration of multiple enterprises within IFS models can lead to an increase in GWP, it simultaneously reduces GHGI, indicating a more sustainable approach to food production. For instance, the M10 model, despite having the highest GWP (10.1 Mg CO2 eq ha^{-1}), recorded the lowest GHGI (0.164 kg CO2 eq kg^{-1} food production), reflecting its efficiency in mitigating greenhouse gas emissions. Additionally, all designed IFS models demonstrated a 63–70% higher EEI compared to the traditional rice-wheat system (M1), with the M9 model achieving the highest EEI (44.1 INR kg GHG^{-1}). These findings suggest that IFS not only enhances food production but also contributes to climate resilience by reducing the overall environmental footprint of agricultural activities.

Conclusion

Integrated Farming Systems (IFS) offer a sustainable solution for agriculture by significantly enhancing food production, employment, and environmental conservation. IFS models, particularly those integrating multiple enterprises like crops, livestock, and biogas units, yield 2–6 times more food than traditional systems while providing year-round employment and reducing economic risks. IFS also improves soil health through effective residue recycling and reduced reliance on external inputs. Though integrating more enterprises may increase global warming potential (GWP), it substantially lowers greenhouse gas intensity (GHGI) and boosts eco-efficiency. These findings highlight IFS as a key strategy for meeting future agricultural needs sustainably.

Future research directions

- **Optimizing IFS Design:** Explore the best combinations of crops, livestock, and other components to enhance productivity and reduce environmental impact.
- **Scaling and Climate Adaptation:** Investigate methods to expand IFS practices and integrate climate resilience for better adaptation to environmental changes.
- **Assessing Long-Term Socio-Economic Benefits:** Evaluate the sustained effects of IFS on employment, income, and livelihoods across different regions.
- **Conducting Life Cycle Evaluations:** Assess the full environmental impact of IFS through detailed life cycle analyses.
- **Policy Development and Community Integration:** Study policies for promoting IFS adoption and examine the potential of community-driven IFS models for shared resource management.

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