

1 | **Integrated farming systems for environment sustainability – A**

2 | **Comprehensive Review**

3 | **Abstract**

4 | This review article explores the holistic approach of Integrated Farming Systems (IFS) as
5 | a sustainable strategy for meeting diverse agricultural demands while ensuring
6 | environmental sustainability. Characterized by the integration of crops, livestock, fishery,
7 | and allied activities within a single farm, IFS is hypothesized to enhance farm resilience,
8 | livelihoods, food security, and ecosystem services. The literature review reveals that IFS
9 | can significantly improve farm profitability (265%) and employment (143%) compared
10 | to single enterprise farms. Furthermore, IFS contribute to nutrient recycling, reducing
11 | external input purchases and enhancing soil quality indicators. The adoption of IFS plays
12 | a crucial role in biodiversity conservation, improves soil organic carbon, and contributes
13 | to reducing greenhouse gas emissions. Despite its advantages, challenges in adoption
14 | include the need for skills, knowledge, resources, labor, and capital among small and
15 | marginal farmers. The study emphasizes the importance of integrating productivity,
16 | profitability, and environmental sustainability variables in a unified evaluation framework
17 | to enhance the adaptability of IFS. In conclusion, IFS emerges as a holistic and climate-
18 | resilient model with the potential for sustainable agriculture, requiring continued
19 | research, policy support, and innovative strategies for widespread adoption.
20 |

21 | **Keywords:** Integrated farming system, biodiversity conservation, greenhouse gas
22 | emissions, environmental sustainability, Climate resilient model

23 | **Introduction:**

24 | Sustainable food systems prioritize meeting current food needs without harming the
25 | planet or compromising future generations' ability to meet theirs. They are defined as
26 | socially, economically, and ecologically sustainable by the FAO, focusing on delivering
27 | food security and nutrition while safeguarding economic, social, and environmental
28 | foundations. This involves ensuring food safety and nutrition through considerations of

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1 production, processing, distribution, and consumption, making food accessible for
2 everyone. The system aims to enhance the quality of life through profitable production,
3 resource protection, efficient use of nonrenewable and on-farm resources, and cost-
4 effective food production by minimizing total energy use.

5 **Need of Sustainability in Integrated Farming Systems**

6 Agriculture not only contributes to climate change and global warming but also causes
7 more carbon dioxide, methane, and nitrous oxide emissions, acidification, eutrophication,
8 nutrient releases, fertilizer residues, and carbon emissions and negatively affects water
9 supplies through runoff and wasteful irrigation systems. Modern industrial agriculture has
10 increased yields and food availability and achieved remarkable growth over time, but
11 existing food systems have also led to many problems, such as pollution and degradation
12 of soils, nitrogen and phosphorus pollution, loss of biodiversity and global habitat,
13 destruction of habitat, rendering agricultural landscapes less resilient, reduction in human
14 health and farm incomes, and shrinkage of water storage and distribution capacity, which
15 have come at a staggering cost to the environment.

16 **Impact of agriculture on environment**

17 The ecological environment encompasses the size and quality of soil, water, climate, and
18 living resources essential to life. While food systems deplete the natural resources on
19 which they rely and diminish the availability of resources needed for other activities,
20 irrigation use disturbs river flow, alters water quality, and modifies regional climates. At
21 the same time, fertilizers leach into surface- and groundwater and cause algal blooms;
22 human-made materials and substances can lead to contamination and create unforeseen
23 problems, affecting air, water, and soil quality.

24 Moreover, large natural areas have been converted to farmland, fragmented habitats have
25 reduced biodiversity, and industrial agriculture has contributed to reducing
26 agrobiodiversity and thus the resilience of ecosystems, wetlands, and wildlife habitats and
27 is a cause for concern due to its lack of respect for life. Monoculture practices directly
28 affect the quality and health of the soil, deplete nutrients, and cause the degradation and
29 pollution of ecosystems and decrease their services.

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1 **Ways to reduce impact of agriculture on environment**

2 Agricultural systems can use natural resources more efficiently and sustainably, reduce
3 the environmental impact of use inputs more efficiently, and achieve a multitude of
4 benefits. It is necessary to maximize production, minimize pollution, avoid uniform
5 fertilizer and pesticide applications, encourage **site-specific practices**, increase **nutrient**
6 **use efficiency**, and **reduce nitrogen application**, as well as protect the natural resource-
7 based agriculture. In this regard, high agricultural productivity should be achieved with
8 low environmental impacts, special emphasis should be placed on improving efficiency
9 in less efficient systems, and new technologies and management techniques should be
10 developed to increase agricultural input efficiency. Achieving sustainable agricultural
11 development requires protecting the ecological capacity, the efficient use of natural,
12 human, material, and energy resources, turning to radically transformative specific
13 innovation policies, and achieving a balance between agricultural development and
14 environmental protection

15 **Worldwide necessity for environmentally sustainable farming practices**

16 It is thought that crop production must be increased by 60–100% by the year 2050 to
17 meet the nutritional needs of a future human population of 9–10 billion. Crop production
18 systems that yield more food of higher nutritional content are needed, yet at the same
19 time, they must have a diminished impact on the environment. Agricultural
20 intensification during the 20th century was through the substantial use of fertilizer,
21 pesticides, and irrigation, all at a significant environmental cost. **These** technologies were
22 part of the Green Revolution that helped achieve food security for billions of people.
23 However, the challenges of the **21st** century are different, and soil and water conservation
24 will be key to achieve food security, and sustainable precision agriculture and
25 environment (SPAEE) will be needed so that intensive agriculture and a changing climate
26 will not generate additional impacts that could contribute to accelerating the pace of a
27 changing climate. As a part of sustainable agriculture, next-generation cropping systems
28 that couple biologically-based technologies (plant-beneficial microbes, cover crops) and
29 precision agriculture (PA) and precision conservation (PC) need to be developed to
30 decrease fertilizer, pesticide, and water inputs while increasing conservation effectiveness

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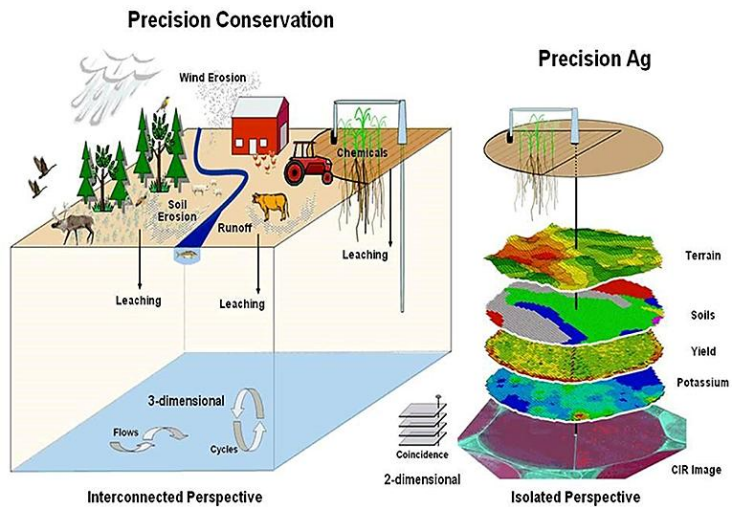
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1 to maintain sustainable agriculture at a field level and sustainability across a watershed.
2 Crop cultivars with enhanced nutritional content and enhanced tolerance to abiotic
3 (drought, salinity, heat, etc.) and/or biotic (disease) stresses need to be developed using
4 advanced breeding and biotechnology approaches. Precision Agriculture (Pierce and
5 Nowak, 1999), Precision Conservation (Berry et al., 2003,2005;Delgado and Berry,
6 2008;Sassenrath and Delgado, 2018) (Figure 1), and sustainable agriculture “are
7 inextricably linked” (Berry et al., 2003,2005;Bongiovanni and Lowenberg-DeBoer,
8 2004). Sustainable agriculture and PC focus on increasing conservation effectiveness and
9 stress environmental impact and sustainability,

10 The 21st century presents formidable challenges to sustainability that humanity
11 will have to confront. The need to increase agricultural production to ensure food security
12 for a global population estimated to grow to 9–10 billion people in the coming decades
13 while confronting a changing climate that threatens sustainability will put pressure on
14 agricultural systems. The United Nations Secretary-General recently warned the global
15 community that climatic changes are occurring at a faster rate than humanity is
16 addressing them and that humanity will be impacted by sea level rise and more extreme
17 weather (United Nations, 2018). Recent reports released by the UN Intergovernmental
18 Panel on Climate Change support these statements (United Nations, 2018). The increased
19 occurrence of extreme weather events will increase the potential for erosion in
20 agricultural systems (Pruski and Nearing, 2002; SWCS, 2003).-Pruski and Nearing
21 (2002)reported that erosion rates could increase by 1.7% for every 1% increase in total
22 rainfall due to climate change. Without conservation practices humanity will not be able
23 to adapt to a changing climate, as conservation practices will be key tools to maintain and
24 increase the productivity and sustainability of agricultural systems (Delgado et al.,
25 2011;Walthall et al., 2012;Spiegel et al., 2018). Big data analysis will also be one of the
26 key tools that will contribute to development of sustainable systems.



1
2 Figure 1. The site-specific approach can be expanded to a three- dimensional scale
3 approach that assesses inflows and outflows from fields to watershed and regional scales
4 [Permission granted by Soil Water Conservation Society for reprint from source: (Berry
5 et al., 2003)

6 **KEY OBJECTIVES OF THE REVIEW**

- 7
- 8 1. Explore the holistic approach of Integrated Farming Systems (IFS) for meeting
9 agricultural demands while ensuring environmental sustainability.
 - 10 2. Assess the economic benefits of IFS, comparing farm profitability (265%) and
11 employment (143%) with single enterprise farms.
 - 12 3. Investigate the environmental impact of IFS, including nutrient recycling, soil
13 quality enhancement, biodiversity conservation, and greenhouse gas emissions
14 reduction.
 - 15 4. Identify challenges in IFS adoption, such as skills, knowledge, resources, labor, and
16 capital constraints among small and marginal farmers.
 5. Highlight IFS as a holistic and climate-resilient model for sustainable agriculture.

1 6. Propose future research, policy support, and innovative strategies for widespread IFS
2 adoption.

3 **Integrated farming systems: Historical Perspective**

4 The roots of the Integrated Farming System can be traced back to the estate of
5 Lautenbach, F.R.G. (Federal Republic of Germany), situated in the district Ortenau of
6 Baden-Württemberg, Germany, where a paradigm shift unfolded in 1978. At this
7 juncture, a deliberate departure from the conventional farming practices marked the
8 initiation of a distinctive low-input farming system—Integrated Farming—contrasting
9 with the traditional approach. This innovative project aimed to underscore the disparities
10 in productivity and ecological impacts between the "integrated" and "conventional"
11 farming systems. Originating from a growing awareness of environmental concerns
12 associated with conventional farming, this approach drew inspiration from research on
13 Integrated Pest Management dating back to the 1920s. The late 1970s witnessed the
14 launch of comprehensive, large-scale, and coordinated integrated agricultural trials across
15 Europe, with the Netherlands being particularly active (Holland et al., 1994). The United
16 Kingdom also embraced the integrated farming paradigm, initiating a project in 1981 to
17 demonstrate its potential. This endeavor culminated in the amalgamation of seven
18 projects in 1994, giving rise to the Integrated Arable Crop Production Alliance (IACPA).
19 The IACPA aimed to streamline research efforts, foster information exchange, eliminate
20 redundant work, and facilitate the swift dissemination of research findings to farmers.
21 The essence of the IFS concept lies in the principle that "there is no waste" and "waste is
22 only a misplaced resource." This underscores the emphasis on leveraging waste as a
23 valuable component in the creation of diverse products. IFS, positioned as a middle
24 ground between organic and conventional farming, relies on foundational principles and
25 procedures rather than adhering to a rigid, prescriptive approach. At its core, IFS
26 integrates crop cultivation, livestock management, and fisheries, crafting a holistic
27 approach to farming that represents a novel, third way between organic and conventional
28 farming methodologies (Morris and Winter, 1999).

29 **Components of IFS and synergistic effect on environment sustainability:**

1 The dwindling profitability in agriculture poses a significant challenge, particularly in
2 arid and semi-arid regions. **Integrated Farming System (IFS)** emerges as a promising
3 solution to enhance profitability by either reducing production costs or boosting
4 productivity through sustainable management practices. IFS achieves cost reduction by
5 effectively recycling wastes, transforming by-products from one enterprise into inputs for
6 others (Manjunath and Itnal, 2003; Ravisankar et al., 2007) and minimizing reliance on
7 external inputs (Ryschawy et al., 2012; Wilkins, 2008). Meena et al. (2018) emphasizes
8 that the agricultural system, rooted in the idea of enhancing people's capacity to manage
9 change, involves developing their ability to learn and improve problem-solving skills.
10 Integrated system research considers various enterprises and resource inputs on the farm,
11 strategically planning crop production, selecting cropping systems, and combining
12 enterprises to establish integrated farming systems that foster sustainable agricultural
13 production. Addressing the impact of climate change on crop yields, Gangwar et al.
14 (2013) assert that IFS approaches sustainability in agriculture. It leverages crop residues
15 for animal feed, emphasizing the importance of agricultural productivity enhancement
16 through the utilization of livestock manure to intensify nutrients, improve soil fertility,
17 and reduce reliance on chemical fertilizers (Gupta et al., 2012). The integration of diverse
18 enterprises within IFS leads to greater sustainability in farm production by recycling
19 wastes within the system, reducing dependence on external high-energy inputs, and
20 conserving natural resources. This multifaceted farming system offers a continuous
21 income stream to farmers throughout the year, derived from the disposal of various
22 products such as eggs, edible mushrooms, milk, honey, and silkworm cocoons, mitigating
23 dependency on a single enterprise and decreasing the risk associated with money lenders
24 (Devendra, 2002). IFS is recognized as a resource management strategy, aiming to
25 achieve economic and sustained production while meeting diverse farm household
26 requirements and preserving the resource base. It can be adopted as a micro-business by
27 farm youth to secure regular income, effectively reducing the risk of failure inherent in
28 single-component or single-crop-based businesses and offering additional benefits,
29 including the efficient recycling of residues within the farm to decrease production costs
30 per unit area (Khan et al., 2012).

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31 **Environmental Impact Assessment**

1 Cutting-edge agricultural production technologies, like **Integrated Farming Systems**
2 **(IFS)**, stand out as environmentally resilient approach. IFS facilitate efficient resource
3 recycling and contribute to a circular economy, holding the potential to enhance food and
4 nutritional security without compromising the quality of the environment. The IFS
5 model, aligned with the principles of a circular economy, operates on the ethos of
6 minimizing waste and maximizing resource recycling (Rathore et al., 2022; Babu et al.,
7 2023). By significantly reducing external input reliance, IFS mitigates negative
8 environmental impacts, showcasing its commitment to sustainability (Babu et al., 2019).
9 The adoption of a circular economy-driven agricultural production model, exemplified by
10 IFS, not only yields ecological benefits but also brings about societal and financial
11 advantages (Babu et al., 2023). IFS is an intricate nexus of soil, plants, animals, tools,
12 power, labor, capital, and other inputs managed by farming families, influenced by
13 various external factors like political, economic, and institutional dynamics at the farm
14 level. It serves as a comprehensive integration of diverse farm enterprises, including
15 crops, animal husbandry, fisheries, forestry, sericulture, and poultry, aiming for optimal
16 resource utilization (Paramesh et al., 2022). Diversified agricultural systems, blending
17 livestock and crops, emerge as an ideal strategy to fortify resilience within agricultural
18 production systems (Sahoo et al., 2019; Babu et al., 2023). In the face of escalating
19 challenges like land degradation and climate change, fostering climate-resilient
20 agriculture through an integrated approach becomes imperative to secure food supplies
21 for the growing global population. IFS, with its diversified enterprises, establishes a
22 stable and sustainable production system, thereby minimizing risks and enhancing
23 resilience to the impacts of climate change (Behera and France, 2016). The integration of
24 crops with livestock not only amplifies ecosystem services but also minimizes
25 environmental footprints, ensuring the sustained profitability of farms. In specific
26 instances, such as combining livestock with areca nut cultivation, IFS enhances
27 ecosystem services and mitigates ecological imbalances resulting from climate change
28 scenarios in coastal agro-ecosystems (Sujatha and Bhat, 2015).

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30 **Adoption strategies to climate change**

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

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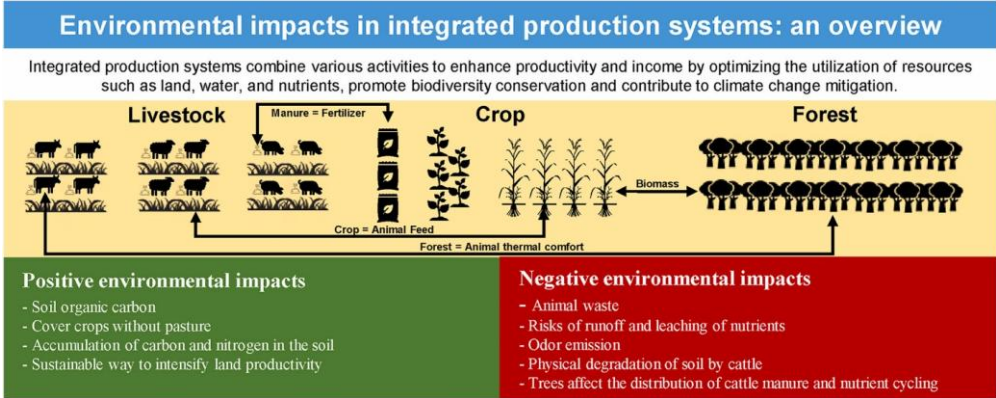


Fig 2: Source: <https://www.sciencedirect.com/science/article/pii/S0959652623025581>

CASE STUDY: IFS-Nurturing Environmental Resilience in Coastal West Bengal

Integrated Farming Systems (IFS) and Environmental Benefits: This exhaustive exploration meticulously examines the profound impact of **Integrated Farming Systems (IFS)** on environmental benefits within the unique context of Coastal West Bengal, India. Focusing keenly on 140 farms, the research unravels critical insights into the sustainability indicators, challenges, adaptive responses, and the nuanced farm typology prevalent in the coastal saline region.

Importance of IFS and Environmental Stewardship: The study passionately underscores the pivotal role played by IFS in addressing the diverse challenges faced by smallholder farmers entrenched in stressed ecosystems. Emphasizing IFS as a linchpin for the enduring sustainability of coastal agroecosystems, it accentuates the imperative need for in-depth exploration into the intricacies of IFS, particularly in the context of environmental stewardship.

Sustainability Assessment and Environmental Impact: Through a meticulous evaluation of 140 IFS, the research employs a synthesized indicator framework tailored specifically for small-scale farms. Noteworthy are the farms exemplifying high sustainability, showcasing adept management of sweet water, on-farm biomass production, and the steadfast adoption of sustainable farming practices, thereby positively influencing the environmental landscape.

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1 **Key Sustainability Indicators for Environmental Well-being:**Critical indicators such
2 as farm size, soil fertility, and non-farm income emerge as pivotal factors shaping the
3 environmental sustainability of IFS. The study unveils diverse pathways to environmental
4 sustainability, effectively capturing the intricate nature of different farm types and their
5 impact on the surrounding ecology.

6 **Challenges and Adaptive Responses for Environmental Resilience:**Acknowledging
7 the intricate nature of assessing sustainability in small-scale farms, the study underscores
8 the need for a meticulously designed indicator framework and a composite index to
9 adeptly capture the multifaceted intricacies across varying spatio-temporal scales. It
10 further emphasizes the role of adaptive responses in fostering environmental resilience.

11 **Integrated Farming Systems and Environmental Adaptation:**Farming in the coastal
12 saline region confronts unique challenges, including frequent inundation, heightened soil
13 salinity, water scarcity, and flood-like situations. The adaptive response, characterized by
14 a strategic shift towards integrated farming and resource intensification, not only aims for
15 optimal productivity but also contributes significantly to environmental adaptation and
16 sustainability.

17 **Significance of Sustainability Assessment for Environmental**
18 **Management:**Emphasizing the vital role of sustainability assessment, the study
19 elucidates its integral part in comprehending adaptive responses, pinpointing pressure
20 points, and fortifying system performance, particularly concerning environmental
21 management. It positions such assessments not merely as beneficial but indispensable for
22 steering informed research and extension strategies aimed at environmental preservation.

23 **Conclusion and Future Research Directions for Environmental Conservation:**As the
24 study concludes, it underscores the necessity of unwavering commitment to assessing and
25 meticulously documenting IFS sustainability, with a specific focus on its environmental
26 implications. It conscientiously advocates for future research endeavors that delve deeper
27 into unraveling how the identified farms can actively contribute to 'strong' agricultural
28 sustainability, particularly in terms of environmental conservation, within coastal
29 agroecosystems.

FINDINGS ON IFS FOR SUSTAINABLE DEVELOPMENT

- **Food Production Potential of IFS Models:** Integrated Farming Systems (IFS) implemented by small and marginal farmers demonstrate a reduced dependence on purchased inputs, enhancing their resilience to climate change and potential crop failures. All the designed IFS models outperformed over the rice-wheat system (the existing system). Designed IFS models registered ~2–6 times higher food production over the existing production system (M1) of northwest India. Among the designed IFS models, concurrent rearing of crop + dairy + fishery + poultry + duckery + apiary + boundary plantation along with biogas unit and vermicomposting (M10) resulted in the highest food production (61.5 Mg ha^{-1}) followed by M9 (60.0 Mg ha^{-1}), M7 (59.5 Mg ha^{-1}), and M6 (58.2 Mg ha^{-1}).

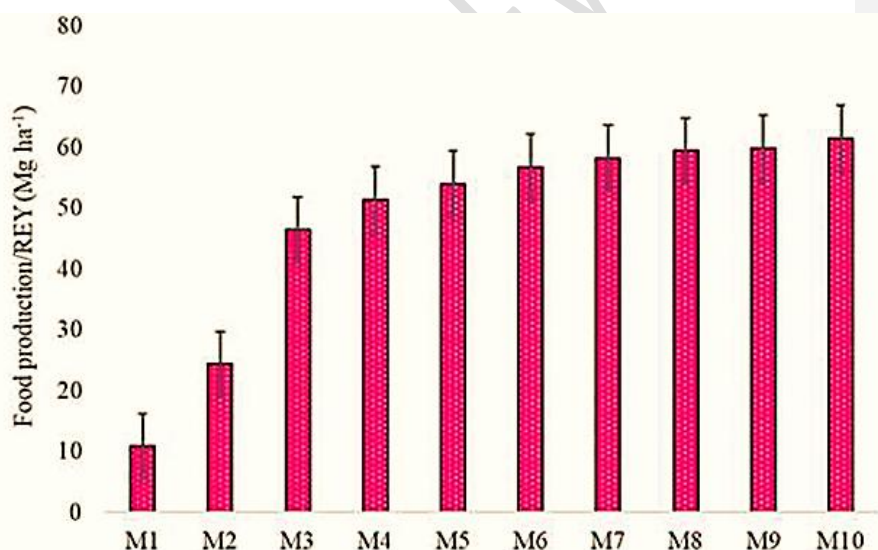


Fig 3: Food production potential of different IFS models. The error bars indicate the standard error between the treatment. M1—rice-wheat system; M2—crop enterprise; M3—crop + dairy; M4—crop + dairy + fishery; M5—crop + dairy + fishery + poultry; M6—crop + dairy + fishery + poultry + duckery; M7—crop + dairy + fishery + poultry + duckery + apiary; M8—crop + dairy + fishery + poultry + duckery + apiary + boundary plantation; M9—crop + dairy + fishery + poultry + duckery + apiary + boundary plantation + biogas unit; M10—crop + dairy + fishery + poultry + duckery + apiary + boundary plantation + biogas unit + vermicompost.

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- 1 • **Effect of IFS on Employment generation:** Integrated Farming Systems (IFS)
2 present a viable solution to mitigate economic risks while enhancing employment
3 opportunities. The ongoing labor demand for managing diverse crops and
4 livestock within the system offers increased employment possibilities, ensuring
5 continuous engagement of farm families in agricultural activities. This becomes
6 particularly relevant in times of economic uncertainties, such as the COVID-19
7 pandemic, providing employment options for reverse migrants transitioning from
8 urban to rural areas. IFS sustains year-round farm activities, effectively involving
9 farm families throughout the year. Das et al. (2013) observed significant
10 enhancements in employment, income, and overall livelihood when implementing
11 pig-based IFS and crop-fish-duck systems compared to sole cropping. Likewise,
12 Surve et al. (2014) demonstrated that adopting IFS offers a promising and
13 financially rewarding alternative to existing cropping systems, delivering higher
14 returns, water productivity, employment opportunities, and energy output.
- 15 • **Effect of IFS on Residue recycling and soil health:** There is empirical support
16 for the positive economic outcomes resulting from crop-animal interactions,
17 fostering sustainable agriculture and environmental conservation (Devendra,
18 2002; Herridge et al., 2019). The intensification of agriculture has led to
19 environmental degradation in economically developed countries, primarily due to
20 the excessive use of high-energy inputs like fertilizers and pesticides. Enhancing
21 the sustainability of farming processes can be achieved by incorporating locally
22 available inputs and integrating them with minimal external inputs, thereby
23 reducing reliance on market resources. **Integrated Farming Systems (IFS)** emerge
24 as a strategic resource management approach to achieve this goal and enhance soil
25 health (Hens & Begossi, 2008; Hu et al., 2016; Paramesh, Arunachalam, et al.,
26 2019; Paramesh, Parajuli, et al., 2019). Studies by Shekinah et al. (2005) and
27 Sujatha and Bhat (2015) have documented improvements in nutrient use
28 efficiency, nutrient recycling, and increased soil microbial activity through the
29 integration of livestock, fisheries, and crops.
- 30 • **Effect of IFS on Climate:** The global warming potential (GWP), greenhouse gas
31 intensity (GHGI), and eco-efficiency index (EEI) were significantly influenced by

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enterprise integration in different IFS models (Table 1). Integration of more enterprises increased the GWP of different IFS models. M2 had the lowest GWP (7.8 Mg CO₂ eq ha⁻¹); however, M10 had the highest GWP (10.1 Mg CO₂eq ha⁻¹), which was almost similar to M9 and M8. On the other hand, increase in the number of enterprises considerably reduced the GHGI over M1. The M10 had the lowest GHGI (0.164 kg CO₂ eq kg⁻¹ food production) followed by M9 (0.169 kg CO₂ eq kg⁻¹ food production). The designed system had ~ 2–5 times less GHGI over M1 (the existing system). Concerning EEI, the lowest EEI (13.2 INR kg GHG⁻¹) was reported in M1. All the designed IFS models recorded 63–70% higher EEI over M1. Among the tested IFS models, M9 registered the maximum EEI (44.1 INR kg GHG⁻¹) closely followed by M5, M6, M7, M8, and M10.

Treatment	Global warming potential (Mg CO ₂ eq. ha ⁻¹)	GHGI (kg CO ₂ eq per kg food production)	Eco-efficiency index (INR per kg CO ₂ eq)
M1	8.10 ± 0.439	0.743 ± 0.156	13.2 ± 8.16
M2	7.80 ± 0.534	0.320 ± 0.023	36.3 ± 0.85
M3	9.10 ± 0.123	0.196 ± 0.017	40.8 ± 0.57
M4	9.70 ± 0.067	0.189 ± 0.019	39.5 ± 0.16
M5	9.90 ± 0.130	0.183 ± 0.021	41.6 ± 0.82
M6	10.00 ± 0.162	0.176 ± 0.023	43.5 ± 1.42
M7	10.02 ± 0.168	0.172 ± 0.024	43.5 ± 1.42
M8	10.08 ± 0.187	0.170 ± 0.025	43.6 ± 1.45
M9	10.09 ± 0.190	0.169 ± 0.025	44.1 ± 1.61
M10	10.10 ± 0.193	0.164 ± 0.027	43.9 ± 1.55

± indicates standard deviation between average mean; M1—rice-wheat system; M2—crop enterprise; M3—crop + dairy; M4—crop + dairy + fishery; M5—crop + dairy + fishery + poultry; M6—crop + dairy + fishery + poultry + duckery; M7—crop + dairy + fishery + poultry + duckery + apiary; M8—crop + dairy + fishery + poultry + duckery + apiary + boundary plantation; M9—crop + dairy + fishery + poultry + duckery + apiary + boundary plantation + biogas unit; M10—crop + dairy + fishery + poultry + duckery + apiary + boundary plantation + biogas unit + vermicompost. INR—Indian rupees.

Table 1. Global warming potential, greenhouse gas intensity (GHGI), and eco-efficiency index (EEI) of different IFS models.

CONCLUSION

In essence, the comprehensive findings of this review unequivocally establish **Integrated Farming Systems (IFS)** as a transformative force in fostering sustainable development. IFS models, incorporating diverse components, exhibit a remarkable 2-6 times higher food production than traditional systems, showcasing resilience to climate change. IFS serves as a robust solution, offering substantial employment opportunities year-round, especially crucial during economic uncertainties like the COVID-19 pandemic. Crop-animal interactions in

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1 IFS contribute to sustainable agriculture, reducing reliance on high-energy inputs
2 and fostering improved soil health and nutrient use efficiency. IFS models
3 significantly reduce greenhouse gas intensity, demonstrating 2-5 times less impact
4 compared to traditional systems, showcasing their environmental sustainability. In
5 summary, IFS emerges not only as an agricultural strategy but a holistic approach
6 addressing economic, environmental, and societal dimensions, thereby playing a
7 pivotal role in shaping a more sustainable and resilient future for agriculture.

8 9 **FUTURE RESEARCH DIRECTIONS**

- 10 ✓ **Optimization of IFS Components:** Investigate the optimal combination
11 and management of diverse components within IFS models to maximize
12 food production potential while minimizing environmental impact. This
13 involves fine-tuning the integration of crop, livestock, fishery, and other
14 elements for optimal resource utilization.
- 15 ✓ **Long-Term Socio-Economic Impact:** Conduct longitudinal studies to
16 assess the long-term socio-economic impact of IFS on farm families.
17 Explore how IFS contributes to sustained employment, income, and
18 livelihood improvements over extended periods, considering different
19 agroecological contexts.
- 20 ✓ **Scaling Up IFS Practices:** Explore strategies for scaling up successful
21 IFS practices, especially those with high food production potential and
22 positive socio-economic impacts. This involves understanding the
23 scalability of IFS models across diverse geographical regions and farm
24 sizes.
- 25 ✓ **Integrated Climate Resilience Strategies:** Investigate the integration of
26 climate-resilient strategies within IFS models to enhance their
27 adaptability to changing climate conditions. Assess the effectiveness of
28 different components in mitigating climate-related risks and promoting
29 sustainable agriculture.
- 30 ✓ **Life Cycle Assessment of IFS:** Conduct a comprehensive life cycle
31 assessment of IFS models to evaluate their environmental impact

1 throughout the entire production cycle. This involves assessing inputs,
2 outputs, and environmental footprint to provide a holistic understanding
3 of the sustainability of IFS practices.

- 4 ✓ **Policy Implications for IFS Adoption:**Examine the policy implications
5 and incentives necessary for promoting widespread adoption of IFS.
6 Evaluate how supportive policies can encourage farmers to transition
7 towards integrated farming practices, considering the unique challenges
8 faced by small and marginal farmers.
- 9 ✓ **Community-Based IFS Models:**Explore the feasibility and impact of
10 community-based IFS models, especially in areas with shared resources
11 and challenges. Investigate how collaborative efforts among farmers can
12 enhance the overall sustainability and resilience of integrated farming
13 systems.

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Comment [KK10]: I am not sure if this is a journal requirement. Why are some year in bold face?