Integrated farming systems for environment sustainability: A Comprehensive Review

Abstract

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

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

Introduction :

Sustainable food systems prioritize meeting current food needs without harming the planet or compromising future generations' ability to meet theirs. They are defined as socially, economically, and ecologically sustainable by the FAO, focusing on delivering food security and nutrition while safeguarding economic, social, and environmental foundations. This involves ensuring food safety and nutrition through considerations of production, processing, distribution, and consumption, making food accessible for everyone. The system aims to enhance the quality of life through profitable production, resource protection, efficient use of nonrenewable and on-farm resources, and cost-effective food production by minimizing total energy use.

Need of Sustainability in Integrated Farming Systems

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

Impact of agriculture on environment

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

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

Ways to reduce impact of agriculture on environment

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

Worldwidenecessity for environmentally sustainable farming practices

It is thought that crop production must be increased by 60–100% by the year 2050 to meet the nutritional needs of a future human population of 9–10 billion. Crop production systems that yield more food of higher nutritional content are needed, yet at the same time, they must have a diminished impact on the environment. Agricultural intensification during the 20th century was through the substantial use of fertilizer, pesticides, and irrigation, all at a significant environmental cost. These technologies were part of the Green Revolution that helped achieve food security for billions of people. However, the challenges of the 21st century are different, and soil and water conservation will be key to achieve food security, and sustainable precision agriculture and environment (SPAE) will be needed so that intensive agriculture and a changing climate will not generate additional impacts that could contribute to accelerating the pace of a changing climate. As a part of sustainable agriculture, next-generation cropping systems that couple biologically-based technologies (plant-beneficial microbes, cover crops) and precision agriculture (PA) and precision conservation (PC) need to be developed to decrease fertilizer, pesticide, and water inputs while increasing conservation effectiveness to maintain sustainable agriculture at a field level and sustainability across a watershed. Crop cultivars with enhanced nutritional content and enhanced tolerance to abiotic (drought, salinity, heat, etc.) and/or biotic (disease) stresses need to be developed using advanced breeding and biotechnology approaches. Precision Agriculture (Pierce and Nowak, 1999), Precision Conservation (Berry et al., 2003, 2005; Delgado and Berry, 2008; Sassenrath and Delgado, 2018) (Figure 1), and sustainable agriculture "are inextricably linked" (Berry et al., 2003, 2005; Bongiovanni and Lowenberg-DeBoer, 2004). Sustainable agriculture and PC focus on increasing conservation effectiveness and stress environmental impact and sustainability,

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

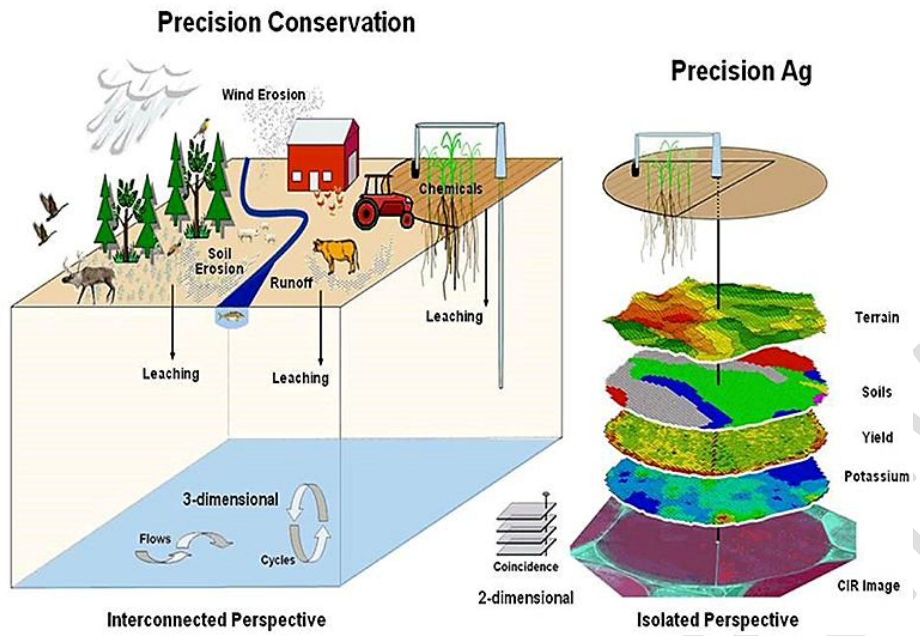


Figure 1. The site-specific approach can be expanded to a three- dimensional scale approach that assesses inflows and outflows from fields to watershed and regional scales [Permission granted by Soil Water Conservation Society for reprint from source: (Berry et al., 2003)

KEY OBJECTIVES OF THE REVIEW

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

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

Integrated farming systems: Historical Perspective

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

Components of IFS and synergistic effect on environment sustainability:

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

Environmental Impact Assessment

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

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). 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. Similar findings were also reported by Kassie et al. and Wossen et al.

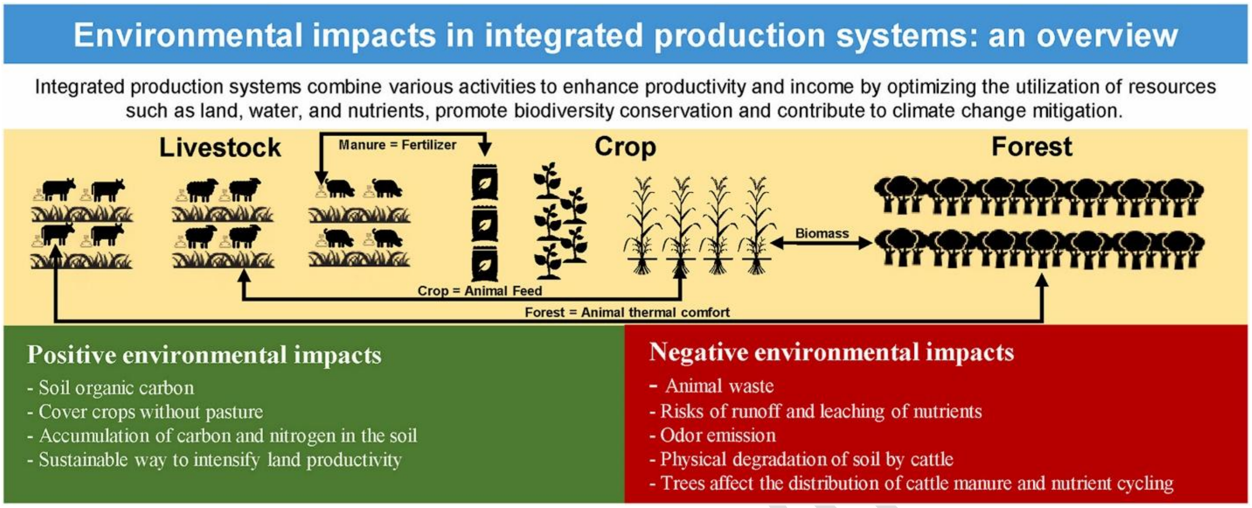


Fig 2:Environmental impacts in integrated production systems : an overview

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.

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

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

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

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

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

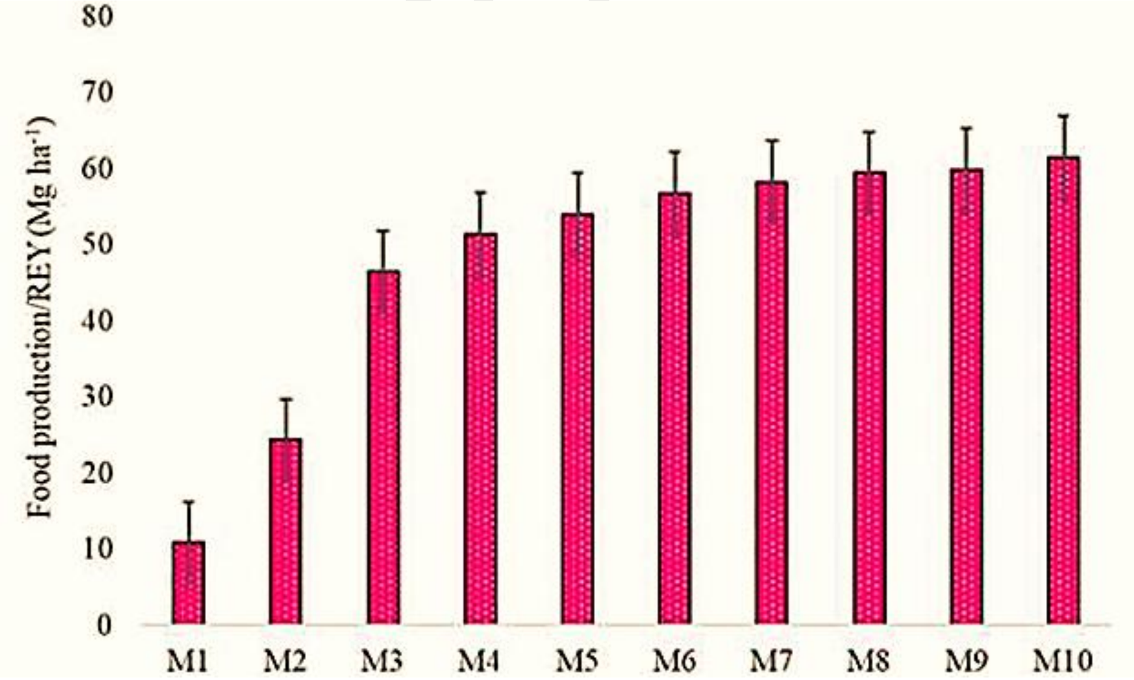


Fig 3: Food production potential of different IFS models. The error bars indicate the standard error between the treatment. M1—rice–wheat system; M2—crop enterprise; M3—crop + dairy; M4—crop + dairy + fishery; M5—crop + dairy + fishery + poultry; M6—crop + dairy + fishery + poultry + duckery; M7—crop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

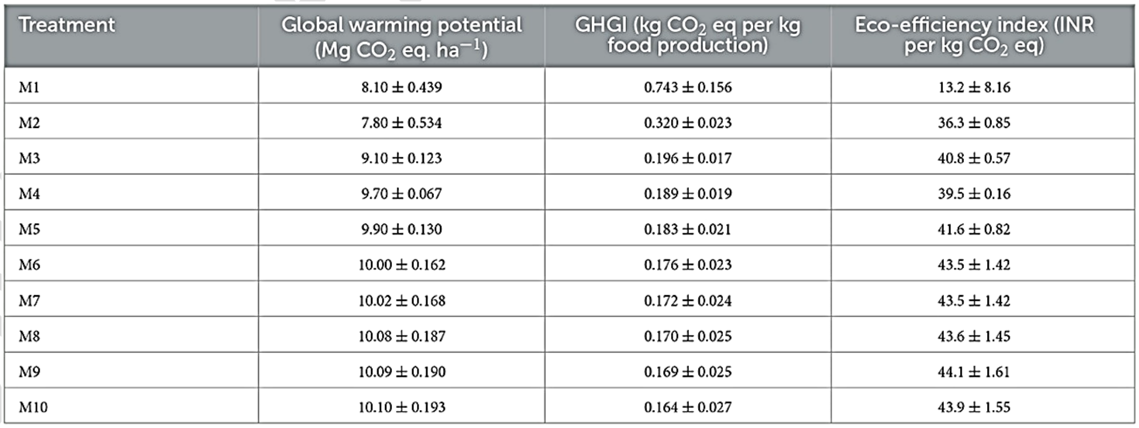
plantation; M9—crop + dairy + fishery + poultry + duckery + apiary + boundary plantation + biogas unit; M10—crop + dairy + fishery + poultry + duckery + apiary + boundary plantation + biogas unit + vermicompost.

- **Effect of IFS on Employment generation:** Integrated Farming Systems (IFS) present a viable solution to mitigate economic risks while enhancing employment opportunities. The ongoing labor demand for managing diverse crops and livestock within the system offers increased employment possibilities, ensuring continuous engagement of farm families in agricultural activities. This becomes particularly relevant in times of economic uncertainties, such as the COVID-19 pandemic, providing employment options for reverse migrants transitioning from urban to rural areas. IFS sustains year-round farm activities, effectively involving farm families throughout the year. Das et al. (2013) observed significant enhancements in employment, income, and overall livelihood when implementing pig-based IFS and crop-fish-duck systems compared to sole cropping. Likewise, Surve et al. (2014) demonstrated that adopting IFS offers a promising and financially rewarding alternative to existing cropping systems, delivering higher returns, water productivity, employment opportunities, and energy output.
- **Effect of IFS on Residue recycling and soil health:** There is empirical support for the positive economic outcomes resulting from crop-animal interactions, fostering sustainable agriculture and environmental conservation (Devendra, 2002; Herridge et al., 2019). The intensification of agriculture has led to environmental degradation in economically developed countries, primarily due to the excessive use of high-energy inputs like fertilizers and pesticides. Enhancing the sustainability of farming processes can be achieved by incorporating locally available inputs and integrating them with minimal external inputs, thereby reducing reliance on market resources. Integrated Farming Systems (IFS) emerge as a strategic resource management approach to achieve this goal and enhance soil health (Hens & Begossi, 2008; Hu et al., 2016; Paramesh, Arunachalam, et al., 2019; Paramesh, Parajuli, et al., 2019). Studies by Shekinah et al. (2005) and Sujatha and Bhat (2015) have documented improvements in nutrient use

efficiency, nutrient recycling, and increased soil microbial activity through the integration of livestock, fisheries, and crops.

- **Effect of IFS on Climate:**The global warming potential (GWP), greenhouse gas intensity (GHGI), and eco-efficiency index (EEI) were significantly influenced by 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 CO_2 eq ha^{-1}); however, M10 had the highest GWP (10.1 Mg CO_2 eq 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 CO_2 eq kg^{-1} food production) followed by M9 (0.169 kg CO_2 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.

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



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.

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

FUTURE RESEARCH DIRECTIONS

- ✓ **Optimization of IFS Components:** Investigate the optimal combination and management of diverse components within IFS models to maximize food production potential while minimizing environmental impact. This involves fine-tuning the integration of crop, livestock, fishery, and other elements for optimal resource utilization.
- ✓ **Long-Term Socio-Economic Impact:** Conduct longitudinal studies to assess the long-term socio-economic impact of IFS on farm families. Explore how IFS contributes to sustained employment, income, and livelihood improvements over extended periods, considering different agroecological contexts.
- ✓ **Scaling Up IFS Practices:**Explore strategies for scaling up successful IFS practices, especially those with high food production potential and positive socio-economic impacts. This involves understanding the scalability of IFS models across diverse geographical regions and farm sizes.
- ✓ **Integrated Climate Resilience Strategies:**Investigate the integration of climate-resilient strategies within IFS models to enhance their

adaptability to changing climate conditions. Assess the effectiveness of different components in mitigating climate-related risks and promoting sustainable agriculture.

- ✓ **Life Cycle Assessment of IFS:**Conduct a comprehensive life cycle assessment of IFS models to evaluate their environmental impact throughout the entire production cycle. This involves assessing inputs, outputs, and environmental footprint to provide a holistic understanding of the sustainability of IFS practices.
- ✓ **Policy Implications for IFS Adoption:**Examine the policy implications and incentives necessary for promoting widespread adoption of IFS. Evaluate how supportive policies can encourage farmers to transition towards integrated farming practices, considering the unique challenges faced by small and marginal farmers.
- ✓ **Community-Based IFS Models:**Explore the feasibility and impact of community-based IFS models, especially in areas with shared resources and challenges. Investigate how collaborative efforts among farmers can enhance the overall sustainability and resilience of integrated farming systems.

REFERENCES

1. Allen, T.; Prosperi, P. Modelling sustainable food systems. Environ. Manag. 2016, 57, 956–975. [CrossRef] [PubMed]
2. Asrat, P.; Simane, B. Adapting smallholder agriculture to climate change through sustainable land management practices: Empirical evidence from North–West Ethiopia. *J. Agric. Sci. Technol. A* **2017**, *7*, 289–301.
3. Asrat, P.; Simane, B. Farmers' perception of climate change and adaptation strategies in the Dabus watershed, North-West Ethiopia. *Ecol. Process.* **2018**, *7*, 7.
4. Babu, S., Das, A., Mohapatra, K. P., Yadav, G. S., Singh, R., Tahashildar, M., et al. (2019). Pond dyke utilization: an innovative means for enhancing productivity and income under integrated farming system in North East Hill Region of India. Indian J. Agric. Sci. 89, 117–122. doi: 10.56093/ijas.v89i1.86190

5. Babu, S., Das, A., Singh, R., Mohapatra, K. P., Kumar, S., Rathore, S. S., et al. (2023). Designing an energy-efficient, economically feasible, and environmentally robust integrated farming system model for sustainable food production in the Indian Himalayas. Sustain. Food. Technol. 1, 126–142. doi: 10.1039/D2FB00016D
6. Behera, U. K., & France, J. (2016). Integrated farming systems and the livelihood security of small and marginal farmers in India and other developing countries. In Advances in agronomy (Vol. 138, pp. 235– 282). Elsevier.
7. Berry, J. K., Delgado, J. A., Khosla, R., and Pierce, F. J. (2003). Precision conservation for environmental sustainability. J. Soil Water Conserv. 58, 332–339.
8. Berry, J. K., Delgado, J. A., Pierce, F. J., and Khosla, R. (2005). Applying spatial analysis for precision conservation across the landscape. J. Soil Water Conserv. 60, 363–370.
9. Bisht, I.S. Agri-food system dynamics of small-holder hill farming communities of Uttarakhand in north-western India: Socioeconomic and policy considerations for sustainable development. Agroecol. Sustain. Food Syst. 2021, 45, 417–449. [CrossRef]
10. Bhargavi, B., & Behera, U. K. (2020). Securing the livelihood of small and marginal farmers by diversifying farming systems. Current Science, 119(5), 854–860.
11. Bongiovanni, R., and Lowenberg-DeBoer, J. (2004). Precision agriculture and sustainability. Prec. Agric. 5, 359–387. doi: 10.1023/B:PRAG.0000040806.39604.aa
12. Chen, W., Wolf, B., Zheng, X., Yao, Z., Butterbach- Bahl, K., Brüggemann, N., Liu, C., Han, S., & Han, X. (2011). Annual methane uptake by temperate semiarid steppes as regulated by stocking rates, aboveground plant biomass and topsoil air per-meability. Global Change Biology, 17(9), 2803– 2816.
13. Crews, T.E.; Carton, W.; Olsson, L. Is the future of agriculture perennial? Imperatives and opportunities to reinvent agriculture by shifting from annual monocultures to perennial polycultures. Glob. Sustain. 2018, 1, e11. [CrossRef]

14. Das, A., Choudhury, B. U., Ramkrushna, G. I., Tripathi, A. K., Singh, R. K., Ngachan, S. V., Patel, D. P., Layek, J., & Munda, G. C. (2013). Multiple use of pond water for enhancing water pro-ductivity and livelihood of small and marginal farmers. Indian Journal of Hill Farming, 26(1), 29– 36.
15. Delgado, J. A., and Berry, J. K. (2008). Advances in precision conservation. Adv. Agron. 98, 1–44. doi: 10.1016/S0065-2113(08)00201-0
16. Delgado, J. A., Groffman, P. M., Nearing, M. A., Goddard, T., Reicosky, D., Lal, R., et al. (2011). Conservation practices to mitigate and adapt to climate change. J. Soil Water Conserv. 66, 118A−129A. doi: 10.2489/jswc.66.4.118A
17. Devendra, C., 2002. Crop-animal systems in Asia: Implications for research. Agricultural Systems 71, 169–177.
18. Dong, Y., Zhang, S., Qi, Y., Chen, Z., & Geng, Y. (2000). Fluxes of CO_2, N2O and CH4 from a typical temperate grassland in Inner Mongolia and its daily variation. Chinese Science Bulletin, 45(17), 1590– 1594.
19. Ebenso, B.; Otu, A.; Giusti, A.; Cousin, P.; Adetimirin, V.; Razafindralambo, H.; Effa, E.; Gkisakis, V.; Thiare, O.; Levavasseur, V.; et al. Nature-based one health approaches to urban agriculture can deliver food and nutrition security. Front. Nutr. 2022, 9, 773746. [CrossRef] [PubMed]
20. European Commission. Farm to Fork Strategy. For a Fair, Healthy and Environmentally Friendly Food System; EU: Brussels, Belgium, 2020.
21. FAO. Sustainable Food Systems-Concept and Framework; FAO: Rome, Italy, 2018
22. FAO. Agriculture and Climate Change: Challenges and Opportunities at the Global and Local Level; FAO: Rome, Italy, 2019.
23. Gandure, S.; Walker, S.; Botha, J.J. Farmers' perceptions of adaptation to climate change and water stress in a South African rural community. *Environ. Dev.* **2013**, *5*, 39–53.
24. Gangwar, L.S., Saran, S., Kumar, S., 2013. Integrated poultryfish farming systems for sustainable rural livelihood security in Kumaon Hills of Uttarakhand. Agricultural Economics Research Reviews 26(Conference Number), 181–188

25. Gupta V, Rai P K and Risam K S. 2012. Integrated crop-livestock farming systems: A strategy for resource conservation and environmental sustainability. Indian Research Journal of Extension Education, 2: 49–54.
26. Hens, L., & Begossi, A. (2008). Diversity and management: from extractive to farming systems. Environment, Development and Sustainability, 10(5), 559–563.
27. Herridge, D. F., Win, M. M., Nwe, K. M. M., Kyu, K. L., Win, S. S., Shwe, T., Min, Y. Y., Denton, M. D., & Cornish, P. S. (2019). The cropping systems of the Central Dry Zone of Myanmar: Productivity constraints and possible solutions. Agricultural Systems, 169, 31– 40.
36. Holland, J.M. (2020). Integrated Farming Systems. Managing Soils and Terrestrial Systems, pp. 171-175). DOI:10.1201/9780429346255-23.
37. Hu, L., Zhang, J., Ren, W., Guo, L., Cheng, Y., Li, J., Li, K., Zhu, Z., Zhang, J., Luo, S., Cheng, L., Tang, J., & Chen, X. (2016). Can the co- cultivation of rice and fish help sustain rice production? Scientific Reports, 6(1), 28728.
38. Kassie, M.; Zikhali, P.; Manjur, K.; Edwards, S. Adoption of sustainable agriculture practices: Evidence from a semi-arid region of Ethiopia. In *Natural Resources Forum*; Wiley Online Library: Hoboken, NJ, USA, 2009; Volume 33, pp. 189–198.
39. Khan, M.H., Kumar, S., Kadirvel, G., Basumatary, R., Bharti, P.K., Dubal, Z.B., 2012. Livelihood improvement of small and marginal farmers through integrated approach of broiler rabbit production in north-east India. International Journal of Bio-resource and Stress Management 3(3), 419–423.
40. Lee, E.K.; Zhang, X.; Adler, P.R.; Kleppel, G.S.; Romeiko, X.X. Spatially and temporally explicit life cycle global warming, eutrophication, and acidification impacts from corn production in the U.S. Midwest. J. Clean. Prod. 2020, 242, 118465. [CrossRef]
41. Liu, C., Holst, J., Brüggemann, N., Butterbach- Bahl, K., Yao, Z., Yue, J., Han, S., Han, X., Krümmelbein, J., Horn, R., & Zheng, X. (2007). Winter- grazing reduces methane uptake by soils of a typical semi- arid steppe in Inner Mongolia, China. Atmospheric Environment, 41(28), 5948– 5958.

42. Manjunath, B.L., Itnal, C.J., 2003. Integrated farming system in enhancing the productivity of marginal rice (Oryza sativa) holdings in Goa. Indian Journal of Agronomy 48, 1–3.
43. Meena, L.R., Kumar, D., Meena, L.K., Singh, K., Singh, S.P., Panwar, A.S., 2018. Integrated farming system model for doubling farmers' income in western Uttar Pradesh. Indian Farming 68(3), 17–19.
44. Morris, C. and Winter, M. (1999). Integrated farming systems: the third way for European agriculture? Land Use Policy. 16(4): 193-205. Stable URL: https://www.sciencedirect.com/science/article/pii/S0264837799000204.
45. Nkonya, E.; Place, F.; Kato, E.; Mwanjololo, M. Climate risk management through sustainable land management in Sub-Saharan Africa. In *Sustainable Intensification to Advance Food Security and Enhance Climate Resilience in Africa*; Springer: Berlin/Heidelberg, Germany, 2015; pp. 75–111.
46. Paramesh, V., Ravisankar, N., Behera, U., Arunachalam, V., Kumar, P., Solomon Rajkumar, R., Dhar Misra, S., Mohan Kumar, R., Prusty, A. K., Jacob, D., Panwar, A. S., Mayenkar, T., Reddy, V. K., & Rajkumar, S. (2022). Integrated farming system approaches to achieve food and nutritional security for enhancing profitability, employment, and climate resilience in India. Food and Energy Security, 11, e321. https://doi.org/10.1002/fes3.321
47. Paramesh, V., Arunachalam, V., & Nath, A. J. (2019). Enhancing eco-system services and energy use efficiency under organic and conventional nutrient management system to a sustainable arecanut based cropping system. Energy, 187, 115902.
48. Paramesh, V., Parajuli, R., Chakurkar, E. B., Sreekanth, G. B., Kumar, H. B. C., Gokuldas, P. P., Mahajan, G. R., Manohara, K. K., Viswanatha, R. K., & Ravisankar, N. (2019). Sustainability, energy budgeting, and life cycle assessment of crop- dairy- fish- poultry mixed farming system for coastal lowlands under humid tropic condition of India. Energy, 188, 116101.
49. Pérez-Escamilla, R. Food Security and the 2015-2030 sustainable development goals: From human to planetary health: Perspectives and opinions. Curr. Dev. Nutr. 2017, 1, e000513. [CrossRef] [PubMed]

50. Pierce, F. J., and Nowak, P. (1999). Aspects of precision agriculture. Adv. Agron. 67:1–85. doi: 10.1016/S0065-2113(08)60513-1
51. Pratama, I.P.; Winarso, H.; Hudalah, D.; Syabri, I. Extended urbanization through capital centralization: Contract farming in palm oil-based agroindustrialization. Sustainability 2021, 13, 10044. [CrossRef]
52. Pruski, F. F., and Nearing, M. A. (2002). Runoff and soil loss responses to changes in precipitation: a computer simulation study. J. Soil Water Conserv. 57, 7–16.
53. Rathore, S. S., Babu, S., Shekhawat, K., Singh, R., Yadav, S. K., Singh, V. K., et al. (2022). Designing energy cum carbon-efficient environmentally clean production system for achieving green economy in agriculture. Sustain. Energy Technol. Assess. 52, 102190. doi: 10.1016/j.seta.2022.102190
54. Ravisankar, N., Pramanik, S.C., Rai, R.B., Nawaz, S., Biswas, T.K., Bibi, N., 2007. Study of an integrated farming system in hilly upland areas of Bay Islands. Indian Journal of Agronomy 52, 7–10.
55. Ryschawy, J., Choisis, N., Choisis, J.P., Joannon, A., Gibon, A., 2012. Mixed crop–livestock systems: an economic and environmental-friendly way of farming?. Animal 6, 1722–1730.
56. Sahoo, A. K., Pattanaik, P., Haldar, D., and Mohanty, U. C. (2019). Integrated farming system: a climate smart agriculture practice for food security and environment resilience. Int. J. Trop. Agric. 37, 193–201.
57. Salton, J. C., Mercante, F. M., Tomazi, M., Zanatta, J. A., Concenço, G., Silva, W. M., & Retore, M. (2014). Integrated crop- livestock system in tropical Brazil: Toward a sustainable production system. Agriculture, Ecosystems& Environment, 190, 70– 79.
58. Sassenrath, G. F., and Delgado, J. A. (2018). “Precision conservation and precision regulation,” in Precision Conservation: Geospatial Techniques for Agricultural and Natural Resources Conservation, eds J. A. Delgado, G. F. Sassenrath, and T. Mueller (Madison, WI: ASA, CSSA, and SSSA).
59. Schönbach, P., Wolf, B., Dickhöfer, U., Wiesmeier, M., Chen, W., Wan, H., Gierus, M., Butterbach- Bahl, K., Kögel- Knabner, I., Susenbeth, A., Zheng, X.,

& Taube, F. (2012). Grazing effects on the greenhouse gas balance of a temperate steppe ecosystem. Nutrient Cycling in Agroecosystems, 93(3), 357–371.

60. Shekinah, D. E., Jayanthi, C., & Sankaran, N. (2005). Physical indi-cators of sustainability— A farming systems approach for the small farmer in the rainfed vertisols of the western zone of Tamil Nadu. Journal of Sustainable Agriculture, 25(3), 43– 65.
61. Shekinah, D. E., & Sankaran, N. (2007). Productivity, profitability and employment generation in integrated farming systems for rainfed vertisols of western zone of Tamil Nadu. Indian Journal of Agronomy, 52(4), 275– 278.
62. Shanmugasundaram, V. S., Baluswamy, M., & Rangaswamy, A. (1995). Integrated farming system research in Tamil Nadu. Journal of Farming Systems Research and Development, 1(1), 1– 9.
63. SWCS (2003). Conservation Implications of Climate Change: Soil Erosion and Runoff From Cropland. A Report From the Soil and Water Conservation Society. Ankeny, IA: Soil and Water Conservation Society.
64. Sujatha, S., & Bhat, R. (2015). Resource use and benefits of mixed farming approach in arecanut ecosystem in India. Agricultural Systems, 141, 126– 137. https://doi.org/10.1016/j.agsy.2015.10.005
65. United Nations (2018). Statement by the Secretary-General on the IPCC Special Report Global Warming of 1.5°C. Available online at: https://www.un.org/sg/en/content/sg/statement/2018-10-08/ statement-secretary-general-ipcc-special-report-global-warming-15-%C2%BAc (accessed October 8, 2018).
66. Walthall, C. L., Hatfield, J., Backlund, P., Lengnick, L., Marshall, E., Walsh, M., et al. (2012). Climate Change and Agriculture in the United States: Effects and Adaptation. USDA Technical Bulletin 1935. Washington, DC: USDA.
67. Wilkins, R.J., 2008. Eco-efficient approaches to land management: a case for increased integration of crop and animal production systems. Philosophical Transactions of the Royal Society B: Biological Sciences 363(1491), 517–525.

68. Wossen, T.; Berger, T.; Di Falco, S. Social capital, risk preference and adoption of improved farm land management practices in Ethiopia. *Agric. Econ.* **2015**, *46*, 81–97.