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Review Article

Integrated Farming Systems as a Climate-Resilient Livelihood Strategy in the Red Lateritic Zone of West Bengal: A Review

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Abstract

Small and marginal farmers form the backbone of Indian agriculture, particularly in the red lateritic zone of West Bengal, where farming systems are increasingly constrained by erratic rainfall, soil degradation, water scarcity, and declining farm incomes under climate change. Integrated Farming Systems (IFS) have emerged as a climate-resilient and eco-friendly approach that integrates crops with allied enterprises such as livestock, poultry, fisheries, horticulture, and agroforestry to enhance resource-use efficiency, livelihood diversification, and system sustainability. This review synthesizes evidence from studies conducted in the red lateritic region, with a specific focus on Purulia district, to characterize prevailing IFS models and assess their performance across social, economic, and ecological sustainability indicators. Four dominant IFS typologies were identified, varying in enterprise composition and scale. Comparative analysis indicates that different IFS configurations deliver distinct benefits: some enhance crop productivity, food and nutritional diversity, and technology adoption, while others strengthen carbon sequestration, reduce dependence on fossil fuels, improve farm profitability, enhance food security, promote gender equity, or reduce women's workload. The review underscores that no single IFS model is universally optimal; rather, sustainability outcomes are highly context-specific and influenced by local agro-ecological conditions, resource availability, and household socio-economic characteristics. The study highlights the need for location-specific, flexible policy frameworks that promote a basket of diversified IFS options to build climate-resilient livelihoods among small and marginal farmers in the red lateritic zone of West Bengal.

Keywords: Integrated Farming Systems; Climate-Resilient Agriculture; Red Lateritic Zone; Small and Marginal Farmers; Sustainable Livelihoods; Livelihood Diversification; Socio-Economic and Ecological Sustainability

Introduction

Small and marginal farmers dominate Indian agriculture and are increasingly vulnerable to climate change due to their reliance on rainfed systems, limited resources, and low adaptive capacity [11,13]. Climate-induced stresses such as erratic rainfall, rising temperatures, and frequent droughts have intensified production risks and livelihood insecurity, particularly in ecologically fragile regions [1,25]. The red lateritic zone of West Bengal, encompassing districts such as Purulia, Bankura, Jhargram, Birbhum, and parts of PaschimMedinipur, represents one of the most climate-sensitive agro-ecological regions in eastern India. The region is characterized by undulating terrain, shallow and coarse-textured soils, low organic carbon, poor nutrient status, and limited water-holding capacity, resulting in low and unstable crop productivity under predominantly rainfed conditions [4,21]. Monocropping of paddy dominates, constraining income diversification and increasing vulnerability to climatic variability [5,36]. Integrated Farming Systems (IFS) have emerged as a climate-resilient and sustainable approach for smallholder agriculture by integrating crops with allied enterprises such as livestock, poultry, fisheries, horticulture, and agroforestry. Recent studies report that IFS enhances resource-use efficiency, nutrient recycling, and farm-level circularity while stabilizing income and improving food and nutritional security [2,24,34]. IFS also contributes to climate adaptation through improved soil health, carbon sequestration, reduced dependence on external inputs, and buffering of climate-induced production risks [19,41]. Evidence from the red lateritic zone of West Bengal indicates that location-specific IFS models improve livelihood diversification, farm profitability, women's participation, and system resilience; however, their performance varies widely across enterprise combinations and socio-economic contexts [3,10,27]. Despite growing interest, a consolidated synthesis of recent evidence on the socio-economic and ecological performance of IFS in this region remains limited. Therefore, this review synthesizes recent literature (2018–2024) on Integrated Farming Systems in the red lateritic zone of West Bengal, with special reference to Purulia district, to identify dominant IFS typologies and evaluate their effectiveness as climate-resilient livelihood strategies for small and marginal farmers.

Integrated farming systems for nutrient recycling and resource-use efficiency

Integrated Farming Systems (IFS) integrate complementary farm enterprises to enhance internal resource recycling and improve overall resource-use efficiency, thereby reducing dependence on external inputs. Recent studies emphasize that recycling of crop residues, animal excreta, pond silt, and on-farm biomass under IFS strengthens nutrient cycling and lowers production costs, particularly for smallholders [2,34]. [2] reported that Diversified IFS models generated substantial quantities of organic residues, which when recycled as farmyard manure and vermicompost significantly improved soil nutrient availability and reduced chemical fertilizer use by 20–30% [2]. Nutrient recycling under IFS enhanced soil organic carbon, microbial activity, and nutrient-use efficiency compared to conventional monocropping systems [24]. Integration of livestock and fisheries contributed significantly to nitrogen and phosphorus recycling through manure application and reuse of nutrient-rich pond water and silt [17]. Resource-use efficiency is further improved through better utilization of water, energy, and labour. Diversified IFS models show higher water-use productivity and lower fossil fuel consumption due to synergistic interactions among enterprises [35]. Similarly, IFS reduces cultivation costs and improves system resilience by minimizing external input dependency while enhancing soil health [40]. Overall, recent evidence confirms that IFS promotes farm-level circularity, making it an effective strategy for nutrient-efficient and sustainable intensification under climate-vulnerable agro-ecosystems.

Integrated farming systems for soil health restoration and long-term sustainability

Sustaining agricultural productivity under climate variability requires maintaining soil physical, chemical, and biological health. Integrated Farming Systems (IFS) play a critical role in soil health improvement through continuous addition and recycling of organic residues generated from multiple farm enterprises. Recycling of crop residues, animal manures, poultry litter, pond silt, and on-farm biomass as compost, vermicompost, or through direct incorporation enhances soil organic carbon, nutrient availability, and microbial activity, while reducing reliance on chemical fertilizers [2,24]. Recent field-based studies have demonstrated significant improvements in soil health parameters under IFS. Kumar., *et al*. reported that a diversified IFS model (crop + horticulture + fishery + poultry) in northeastern India increased soil organic carbon (0.06%) and available N, P, and K by 4, 1, and 4 kg ha^{-1}, respectively, after three years, primarily due to systematic recycling of poultry waste, crop residues, and weeds through vermicomposting [16]. Similarly, Meena., *et al*. observed enhanced soil enzyme activity, microbial biomass carbon, and aggregate stability under IFS compared to conventional cropping systems [23].

Livestock integration further contributes to soil health improvement. Ponnusamy and Devi highlighted that manure and urine generated from integrated livestock enterprises provide substantial economic returns while improving soil aggregation, structure, nutrient availability, and microbial proliferation [32]. More recently, Ravisankar., *et al*. emphasized that regular application of livestock-derived organics under IFS improves soil resilience and nutrient buffering capacity [35]. Vinodakumar., *et al*.

demonstrated that diversified IFS models generated substantially higher crop residues and nutrient additions compared to crop-alone systems, resulting in greater net gains in available soil N, P, and K [42]. Supporting this, Singh., *et al*. reported that long-term adoption of IFS significantly improved soil fertility status and reduced external fertilizer dependency [40]. Overall, recent evidence confirms that IFS is an effective strategy for restoring soil health and ensuring sustainable production through enhanced organic matter recycling, improved nutrient dynamics, and strengthened soil biological activity.

Integrated farming systems as an eco-friendly and low-emission agricultural approach

Intensive, input-driven agriculture has led to widespread environmental degradation through excessive use of chemical fertilizers, pesticides, and energy-intensive practices, resulting in soil degradation, biodiversity loss, and ecological imbalance. Continuous monocropping and cultivation of exhaustive crops have further accelerated depletion of natural resources. In this context, Integrated Farming Systems (IFS) offer an eco-friendly alternative by promoting recycling and reuse of on-farm resources, thereby minimizing waste generation and external input dependency. IFS enables efficient utilization of by-products, where wastes from one enterprise serve as inputs for others or are biologically transformed through composting, vermicomposting, or biogas production. Recycling of crop residues and livestock wastes not only reduces environmental pollution but also substitute's synthetic fertilizers and fossil fuels. Capture of emissions from livestock and dairy units through biogas plants provides renewable energy, while digested slurry enhances soil fertility, contributing to circular and low-carbon agriculture [2,19]. Maintaining diverse enterprises under IFS enhances on-farm biodiversity, which strengthens ecosystem services such as pollination, nutrient cycling, biological pest regulation, microclimate moderation, and landscape resilience [7,41]. Diversified systems are therefore more ecologically stable than specialized monocropping systems. Evidence from integrated rice-based systems highlights the environmental benefits of IFS. Rice–fish integration significantly improved profitability while altering greenhouse gas dynamics, reducing N_2O emissions despite higher CH_4 emissions, and yielding greater economic returns per unit CO_2 equivalent emitted than rice monocropping [6]. More recently, IFS was found to be more effective in reducing greenhouse gas emissions compared to reduced tillage, organic farming, or precision agriculture practices alone [33]. Rice–duck integration studies further confirm the eco-efficiency of IFS. Rice–duck systems achieved a 13.3% reduction in global warming potential along with higher rice yields due to enhanced soil aeration, reduced weed biomass, and suppression of methanogen activity through duck-induced bioturbation [43]. Overall, IFS represents an environmentally sound approach that balances productivity, profitability, and ecological sustainability, making it a key strategy for climate-smart and low-emission agriculture.

Integrated farming systems for sustainable crop production

Sustainable crop production requires farming systems that ensure stable yields while minimizing pressure on natural resources and external inputs. Integrated Farming Systems (IFS) promote sustainability by combining crops with horticulture, livestock, fisheries, and allied enterprises, enabling efficient resource utilization, income diversification, and reduced production risk. Through internal recycling of nutrients and energy, IFS maintains crop productivity without excessive exploitation of soil, water, and energy resources, thereby ensuring long-term farm sustainability and income stability. Recent studies provide strong evidence of the sustainability potential of IFS. A highly diversified IFS model comprising crops, dairy, fishery, poultry, duckery, apiary, boundary plantation, biogas, and vermicompost recorded superior energy efficiency, with high net energy gain, energy profitability, and the lowest greenhouse gas (GHG) intensity (0.164 kg CO_2 eq kg^{-1} food), demonstrating its environmental robustness and suitability for sustainable food production [8]. Similarly, IFS models integrating cropping systems with livestock, boundary plantations, vegetables, and horticulture, vermicomposting, and farm ponds significantly improved farm income, livelihood security, and nutritional outcomes for small and marginal farmers [30]. Integrated production systems also show advantages in energy efficiency and economic sustainability. Rice–fish–turtle co-culture systems were found to be more energy- and cost-efficient than rice monoculture due to synergistic biological interactions and reduced input requirements [20]. Earlier evidence from rice-based IFS in humid regions further supports that integration of crops with poultry, mushroom, and livestock enterprises enhances crop-equivalent yield, employment generation, and overall system sustainability [15]. Overall, IFS emerges as a viable strategy for sustainable crop production by improving productivity, energy efficiency, and environmental performance while ensuring stable livelihoods under diverse agro-ecological conditions.

Integrated farming systems as a tool to meet household needs

Integrated Farming Systems (IFS) play a crucial role in meeting diverse household needs, including food and nutritional security, fuel, energy, income, and livelihood stability, through the integration of complementary farm enterprises. By combining crops with horticulture, livestock, fisheries, poultry, and boundary plantations, IFS enables year-round production of food and essential farm outputs while reducing dependence on market purchases. Panwar., *et al*. developed a one-hectare IFS model for a five-member farm family in the South Bihar Alluvial Plains, integrating diversified cropping, horticulture, dairy, goatry, fishery, ducks, and boundary plantations [29]. The system successfully met the entire household requirement of cereals, pulses, oilseeds, fruits, vegetables, milk, eggs, and fish, in addition to supplying fodder for livestock and fuelwood (4 t yr^{-1}). Recycling of farm wastes generated enriched vermicompost and manure, improving soil health and reducing input costs. The model produced substantial marketable surplus, ensured year-round income (₹13,160–51,950 ha^{-1} $month^{-1}$), reduced purchased inputs to only 21% of total costs, and generated net returns 3.2 times higher than the prevailing crop–dairy system. Sheikh., *et al*. further emphasized that IFS is a major livelihood source for rural households, reporting that specialized IFS models integrating staple crops, short-duration cash crops, vegetables, poultry, and value addition significantly enhanced income stability and livelihood diversification among farming families in Uttar Pradesh [38].

Integrated farming systems for employment generation

IFS contributes substantially to rural employment generation by distributing labour demand throughout the year through diverse and interlinked farm enterprises. Unlike conventional cropping systems that generate seasonal employment, IFS provides continuous on-farm work, particularly benefiting family labour during lean periods. Kumar., *et al*. reported that crop–fish–duck–goat and crop–fish–cattle systems generated 752 and 722 man-days ha^{-1} $year^{-1}$, respectively, significantly higher than conventional rice–wheat systems [18]. Sharma., *et al*. observed that irrigated IFS models generated up to 1,033 man-days compared to 659 man-days under rainfed systems, reflecting the influence of enterprise diversification and intensity of cultivation [39]. Similarly, Govardhan., *et al*. documented that an IFS model comprising crops, dairy, sheep, rabbits, poultry, and quails in Telangana generated 750 man-days ha^{-1}, compared to only 225 man-days under the dominant rice–maize system [12]. Overall, IFS emerges as an effective strategy for meeting household needs and enhancing rural employment by ensuring food self-sufficiency, steady income, and year-round labour engagement, thereby strengthening livelihood resilience among small and marginal farmers.

Integrated farming systems for income generation and profitability

In India, the predominance of small and marginal landholdings often limits farm profitability under mono-cropping systems. Integrated Farming Systems (IFS) enhance farm income by combining multiple enterprises, enabling efficient resource recycling, risk diversification, and year-round cash flow. Vinodakumar., *et al*. demonstrated that an IFS model integrating crops, goats, cattle, poultry, and fisheries generated significantly higher net returns (₹1,89,069 ha^{-1} yr^{-1}) compared to conventional cotton-based farming (₹74,552 ha^{-1} yr^{-1}) [42]. The 2.5-fold increase in income was primarily attributed to the inclusion of livestock and allied enterprises, which provided regular and assured income streams. Similarly, Mitra., *et al*. reported that an IFS model comprising fish culture, duck farming, azolla, and pulses yielded nearly three times higher annual income (₹1,38,673 yr^{-1}) than conventional farming systems (₹45,320 yr^{-1}) [26]. The IFS model also recorded a superior benefit–cost ratio (2.28) compared to the conventional system (1.14), indicating enhanced economic efficiency and sustainability. Kashyap., *et al*. observed a dynamic shift in income contribution within IFS over time [14]. While crop enterprises dominated income generation during initial years, livestock, horticulture, and value-added components progressively contributed a larger share in subsequent years. Increased diversification reduced dependence on a single enterprise, stabilized farm income, and improved overall profitability. Overall, evidence suggests that IFS significantly improves income and profitability for small and marginal farmers by integrating complementary enterprises and promoting diversified, resilient farm economies.

Integrated farming systems as a resilience tool under climate change

Integrated Farming Systems (IFS) enhance farm resilience to climate variability by diversifying enterprises, improving resource-use efficiency, and strengthening adaptive capacity. Process-based simulation studies by Peterson., *et al*. showed that integrating livestock into crop rotations significantly increased system-level productivity and resilience under both historical and projected climate scenarios [31]. Although winter grazing occasionally caused soybean yield penalties (up to 1,200 kg ha^{-1}), the additional income from livestock offset these losses. Overall productivity was higher in integrated systems in 77% of years under historical climate conditions and in 95% of years under future climate scenarios, indicating superior resilience to chronic climate stress and weather anomalies. Nasr., *et al*. reported high climate vulnerability (>80%) in semi-arid rural Tunisia and identified income and food access, adaptive capacity, and asset ownership as key determinants of farm resilience [28]. Access to irrigation and diversification of farm activities—core principles of IFS—were the most effective adaptation strategies, with crop diversification playing a central role in reducing climate risk. Further evidence from Seo, Martin., *et al*. and Gil., *et al*. consistently indicates that integrated farms are more resilient to global warming than specialized systems [9,22,37]. The effective use of family labour, reported by 48.3% of surveyed farmers, enhances adaptive capacity during climate-sensitive operations such as sowing and harvesting. Collectively, these findings establish IFS as a robust strategy for enhancing climate resilience through diversification, livelihood security, and system flexibility

Graphical summary of key findings

The following figures present a graphical synthesis of the economic, employment, environmental, and productivity outcomes of Integrated Farming Systems (IFS) relative to conventional farming in the red lateritic zone of West Bengal. All data are sourced from peer-reviewed studies cited in this review. Mixed bar-and-line charts simultaneously compare absolute values (bars) and derived ratios or percentage improvements (line overlay), enabling multi-dimensional comparison across IFS models and conventional systems.

Conclusion

In the red lateritic zone of Purulia district, West Bengal—characterized by poor soil fertility, low organic carbon, erratic rainfall, and frequent droughts—diversification of existing farming systems through Integrated Farming Systems (IFS) is crucial for sustainable livelihood improvement of small and marginal farmers.

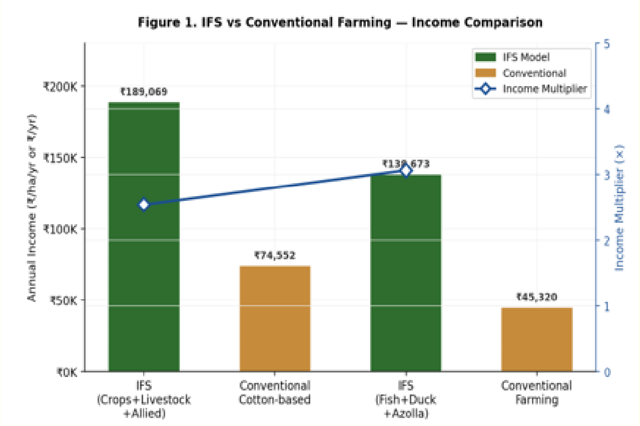

Figure 1: Comparison of annual farm income (₹ ha^{-1} yr^{-1}) under IFS and conventional systems. Bars represent absolute income; the line overlay shows the income multiplier of IFS over its paired conventional benchmark. Note: IFS (Crops + Livestock + Allied) generated ₹1,89,069 ha^{-1} yr^{-1} compared to ₹74,552 under conventional cotton-based farming [42]. IFS (Fish + Duck + Azolla) yielded ₹1,38,673 yr^{-1} compared to ₹45,320 under conventional farming, with a benefit–cost ratio of 2.28 versus 1.14 [26].

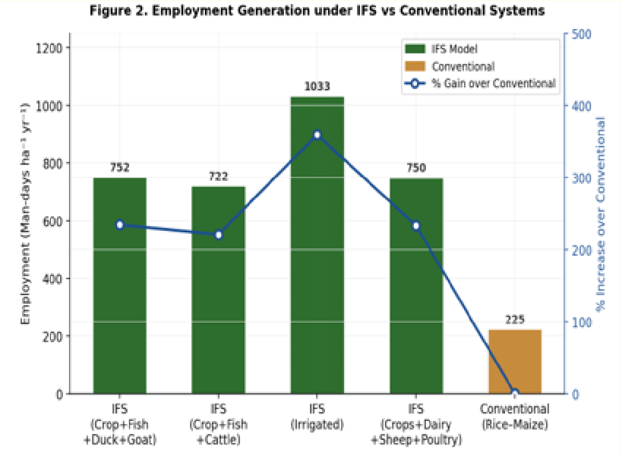

Figure 2: Employment generation (man-days ha^{-1} yr^{-1}) across IFS typologies and the conventional rice–maize system. The line overlay depicts percentage increase in employment over the conventional baseline (225 man-days ha^{-1} yr^{-1}).Note: IFS models generated 722–1,033 man-days ha^{-1} yr^{-1} compared to 225 under the conventional rice–maize system [12,18,39], representing a 221–359% increase in farm employment.

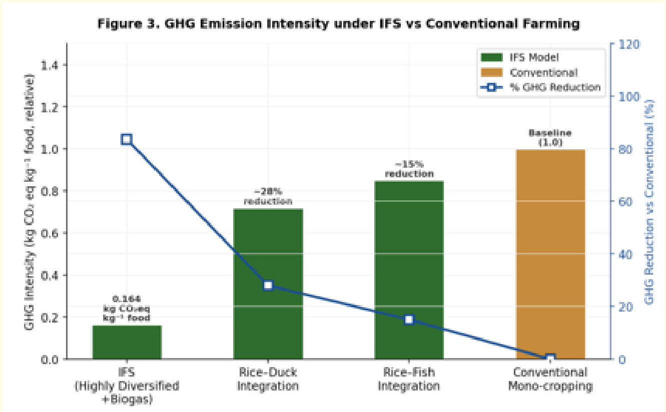

Figure 3: GHG emission intensity (kg CO_2 eq kg^{-1} food, relative to conventional baseline = 1.0) across IFS models. The line overlay shows percentage reduction in GHG emissions relative to conventional mono-cropping. Note: Highly diversified IFS with biogas recorded the lowest GHG intensity of 0.164 kg CO_2 eq kg^{-1} food [8]. Rice–duck integration achieved a 13.3% reduction in global warming potential [43]. Rice–fish integration reduced N_2O emissions relative to rice monoculture [6].

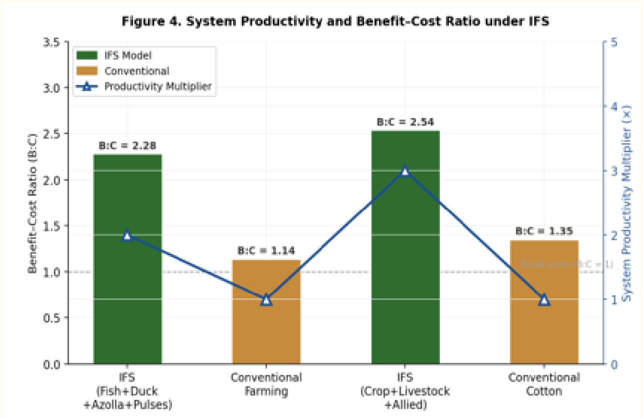

Figure 4: Benefit–cost (B:C) ratio and system productivity multiplier across IFS and conventional farming systems. Bars show B:C ratios; the line overlay presents relative system productivity of IFS over conventional benchmarks. Note: IFS consistently achieved B:C ratios above 2.0 compared to 1.14–1.35 under conventional systems. System productivity improvements of 2–3× over conventional mono-cropping are reported across the reviewed literature [8,26,42].

Integration of suitable crops and cropping systems with livestock, horticulture, kitchen gardens, boundary plantations, and on-farm value addition significantly enhances resource-use efficiency, nutrient recycling, and soil health. Evidence suggests that well-designed IFS models in this region can increase system productivity by 2–3 times and net farm income by 3–5 times over conventional mono-cropping systems, while reducing external input dependency by 40–50%. Additionally, IFS ensures year-round employment, improves household nutritional security, and enhances climate resilience against rainfall variability and temperature extremes. Overall, IFS emerges as a location-specific, ecologically sound, and economically viable strategy for strengthening farm livelihoods and conserving fragile agro-ecosystems in the red lateritic zone of Purulia.

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