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Integrated farming systems in Jharkhand: Current status, scope, and future prospects amid changing agricultural scenarios

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Abstract
Small and marginal farmers form the foundation of Jharkhand's agrarian economy, constituting over 80% of the total farming population while cultivating a limited share of operational land holdings (Government of Jharkhand, 2023). Agriculture in the state is primarily rainfed, characterized by low productivity, fragmented holdings, and high dependence on monsoon rainfall (Birsa Agricultural University, 2022). Despite the hard work and labor-intensive nature of farming, rural livelihoods remain insecure due to limited diversification and low farm income (Chand *et al*., 2017) [10]. In this context, the Integrated Farming System (IFS) has emerged as a promising approach to enhance farm productivity, ensure livelihood security, and promote sustainable use of available resources (Behera *et al*., 2012) [3]. IFS integrates various enterprises such as field crops, livestock, fisheries, horticulture, poultry, beekeeping, and agroforestry into a single farm unit, where the output or by-product of one component serves as an input for another, thereby reducing waste, lowering production costs, and improving overall farm efficiency (Gill *et al*., 2010) [21].

In Jharkhand, the adoption of IFS has shown encouraging results across different agro-climatic zones, particularly in improving income stability, nutritional security, and resource recycling for small and marginal farmers (ICAR-RCER, 2021; Singh *et al*., 2020) [47]. Studies and demonstrations conducted by Krishi Vigyan Kendras (KVKs) and research institutions under ICAR-RCER and Birsa Agricultural University have revealed that integrated farming enhances soil health, optimizes water use, and ensures year-round employment opportunities (ICAR, 2023). The system also contributes to resilience against climatic fluctuations and market uncertainties, which are common challenges in the state (Kumar *et al*., 2019) [33]. Given Jharkhand's diverse topography and resource endowment, promoting region-specific IFS models supported by training, policy incentives, and institutional linkages can transform the state's agriculture from subsistence to a more profitable and sustainable enterprise (NITI Aayog, 2022). In the changing agricultural scenario, integrated farming offers a viable pathway for ecological balance, enhanced livelihood, and inclusive rural development in Jharkhand.

Keywords: Integrated Farming System, Jharkhand, Small and Marginal Farmers, Livelihood Security, Sustainable Agriculture, Climate Resilience, Resource Recycling, Rural Development

Introduction

Agriculture remains the backbone of India's rural economy, supporting nearly half of the workforce and playing a vital role in food security and livelihood generation. However, the sector faces persistent challenges such as fragmented landholdings, declining soil fertility, heavy dependence on monsoon rainfall, and low farm income, particularly among small and marginal farmers (Chand *et al*., 2017; NITI Aayog, 2022) [10]. In India, small and marginal farmers constitute over 85% of the farming population while owning less than 45% of operational land, resulting in resource constraints and low productivity (Government of India, 2023). These challenges necessitate a shift from mono-cropping to diversified and resource-efficient farming systems.

The Integrated Farming System (IFS) has emerged as a holistic and sustainable approach to address these issues. IFS involves the integration of multiple farm enterprises such as crops, horticulture, livestock, fisheries, poultry, and agroforestry within a single farm unit, enabling efficient recycling of resources and reduction of production costs (Gill *et al*., 2010; Behera *et al*., 2012) [21, 3]. By utilizing the by-products of one enterprise as inputs for another, IFS enhances productivity, farm income, employment generation, and environmental sustainability (Reddy & Suresh, 2009).

In Jharkhand, agriculture is predominantly rainfed, with nearly 92% of cultivated land dependent on erratic rainfall and limited irrigation infrastructure (Birsa Agricultural University, 2022). Small and marginal farmers constitute about 80% of the farming population and face frequent crop failures, low productivity, and livelihood insecurity due to poor resource availability and weak market linkages (Government of Jharkhand, 2023; Kumar *et al*., 2019) [33]. These conditions make Jharkhand particularly suitable for the adoption of integrated and diversified farming approaches.

Empirical evidence from ICAR-RCER, Birsa Agricultural University, and Krishi Vigyan Kendras (KVKs) in Jharkhand indicates that IFS models such as crop-livestock-fishery and crop-livestock-horticulture systems generate significantly higher net returns than traditional farming systems while improving soil health, nutrient recycling, and climate resilience (Singh *et al*., 2020; ICAR-RCER, 2021; ICAR, 2023) [47]. Moreover, diversification under IFS contributes to household nutritional security by providing cereals, pulses, vegetables, milk, eggs, and fish (FAO, 2020).

Despite its proven benefits, adoption of IFS in Jharkhand remains limited due to socio-economic constraints, lack of technical knowledge, inadequate institutional support, and market-related challenges. Therefore, a systematic assessment of the performance, scope, and prospects of Integrated Farming Systems in Jharkhand is essential. The present study aims to evaluate the economic viability of IFS models in comparison with prevailing farming systems and assess their potential for enhancing livelihood security and sustainable agricultural development in the state.

Materials and Methods

Study Area

The present study was conducted in Jharkhand, an eastern Indian state where agriculture is predominantly rainfed and characterized by small and marginal landholdings. The state exhibits undulating to plateau topography with lateritic to sandy loam soils and an average annual rainfall ranging between 1,000 and 1,200 mm, most of which is concentrated during the southwest monsoon. These agro-ecological features strongly influence crop choices, enterprise integration, and livelihood strategies of farm households. Small and marginal farmers constitute more than 80% of the farming population, making Jharkhand an appropriate region for assessing the economic viability and sustainability of Integrated Farming System (IFS) models under resource-constrained conditions.

Study Design and Data Sources

A comparative economic assessment approach was adopted to evaluate the performance of Integrated Farming Systems vis-à-vis prevailing traditional farming systems in Jharkhand. The study relied on secondary data collected from peer-reviewed research articles, institutional publications, annual reports, and field evaluation documents published between 2012 and 2025. Data sources included studies and reports from ICAR-RCER, Patna; Birsa Agricultural University, Ranchi; ICAR-ATARI, Patna; and Krishi Vigyan Kendras (KVKs), particularly KVK Ramgarh. Relevant published works by Singh *et al*. (2012, 2020) [47], Behera *et al*. (2013) [4], Kumar *et al*. (2015, 2019) [33], Prasad *et al*. (2017) [59], and ICAR-RCER (2014, 2018, 2021) were systematically reviewed and synthesized.

Data Compilation and Farming System Classification

The compiled dataset comprised 11 paired farming system models, each representing a comparison between a prevailing traditional system and a corresponding Integrated Farming System model implemented under similar agro-ecological conditions. Traditional systems mainly included mono-cropping or low-diversity systems such as rice-fallow, rainfed crop farming, or crop-only systems. The IFS models integrated multiple enterprises such as crops, vegetables, livestock, fisheries, poultry, horticulture, and agroforestry.

For each paired model, annual net returns (₹ ha^{-1} yr^{-1}) were extracted for both traditional and IFS systems. These data were standardized to ensure comparability across locations and years.

Economic Indicators

To assess the economic advantage of IFS adoption, the following indicators were computed:

1. Mean Income Difference (₹ ha^{-1} yr^{-1})

Mean Difference=Net Return (IFS)−Net Return (Traditional)\text{ Mean Difference} = \text{Net Return (IFS)} - \text{Net Return (Traditional)}Mean Difference=Net Return (IFS)−Net Return (Traditional)

2. Percentage Increase Over Traditional System (%)

%Increase=Mean DifferenceNet Return (Traditional)×100\%\text{ Increase} = \frac{\text{Mean Difference}}{\text{Net Return (Traditional)}} \times 100%Increase= Net Return (Traditional) Mean Difference × 100

These indicators were used to quantify income enhancement and relative economic superiority of IFS models over existing farming practices.

Statistical Interpretation

A paired comparison approach was employed, as each IFS model directly corresponded to a specific traditional system under comparable conditions. Statistical interpretation focused on consistency and magnitude of income gains across studies rather than inferential hypothesis testing, given the reliance on multi-source secondary data.

- Income gains exceeding 100% or consistently higher net returns across multiple studies were categorized as "significant improvement".
- Systems exhibiting exceptionally high income enhancement (greater than 150%) with multi-year validation and institutional backing were classified as "highly significant improvement", following criteria adopted in earlier studies (Singh *et al*., 2012; Behera *et al*., 2013; Kumar *et al*., 2019) [33, 3].

Results and Discussion

Integration of Enterprises

Since Integrated Farming System is an interrelated complex matrix of soil, water, plant, animal, and environment and their interactions, it enables the system to be more viable, sustainable, and profitable compared to a sole arable farming system. In Jharkhand, where small and marginal farmers dominate and landholdings are fragmented, integration of different enterprises offers a promising strategy to enhance productivity and ensure livelihood security throughout the year. The income obtained from traditional crop farming alone is often insufficient to sustain farm families year-round. However, assured and regular cash flow becomes possible when crop production is combined with complementary enterprises such as livestock, fishery, poultry, mushroom cultivation, or beekeeping. Judicious integration of enterprises, keeping in view the agro-ecological and socio-economic conditions of the locality, pays greater dividends while promoting effective recycling of crop residues and animal wastes.

To strengthen the food and nutritional security chain in Jharkhand, where deficiencies in vitamins and minerals are common due to limited dietary diversity, the integration of horticultural and vegetable crops plays a crucial role. These crops can produce two to three times more energy per unit area compared to cereals and contribute to balanced nutrition and enhanced farm income. Similarly, the inclusion of beekeeping, fishery, backyard poultry, goatry, duckery, piggery, and mushroom cultivation provides additional income opportunities, improves dietary diversity, and ensures year-round employment.

Integration of enterprises ensures efficient resource recycling particularly of crop residues and animal wastes since about 70-80% of micronutrients remain in the biomass and animal by-products. This nutrient recycling is particularly beneficial in Jharkhand's rainfed and resource-scarce regions, where soil fertility management and sustainability are major challenges.

IFS can be practiced in different forms and intensities depending on the socio-economic status of farmers, soil characteristics, topography, and available resources (Rahman & Sarkar, 2012). Therefore, enterprise selection in Jharkhand should consider the region's diverse agro-climatic zones, market linkages, processing facilities, and farmers' investment capacities. The integration must be designed such that the output or by-product of one enterprise becomes the input of another, resulting in strong complementarities within the system.

Empirical studies in other parts of India have demonstrated significant income enhancement through IFS. For instance, Naik (1998) [40] observed that integrating suitable enterprises into existing farming systems increased net farm returns by 25-150%, and further adoption of improved technologies raised income levels by 40-170%. Similar outcomes can be anticipated in Jharkhand, where integrating enterprises such as crops, livestock, horticulture, fisheries, and small-scale processing units could substantially improve farm profitability and resource-use efficiency.

Efficient Nutrient Recycling

Efficient nutrient recycling is a cornerstone of any sustainable Integrated Farming System (IFS), ensuring optimal utilization of available on-farm resources and minimizing external input dependency. In Jharkhand, where small and marginal farmers predominate and soil fertility is often low due to continuous cultivation and erosion, nutrient recycling within IFS offers a viable pathway for enhancing productivity and maintaining ecological balance.

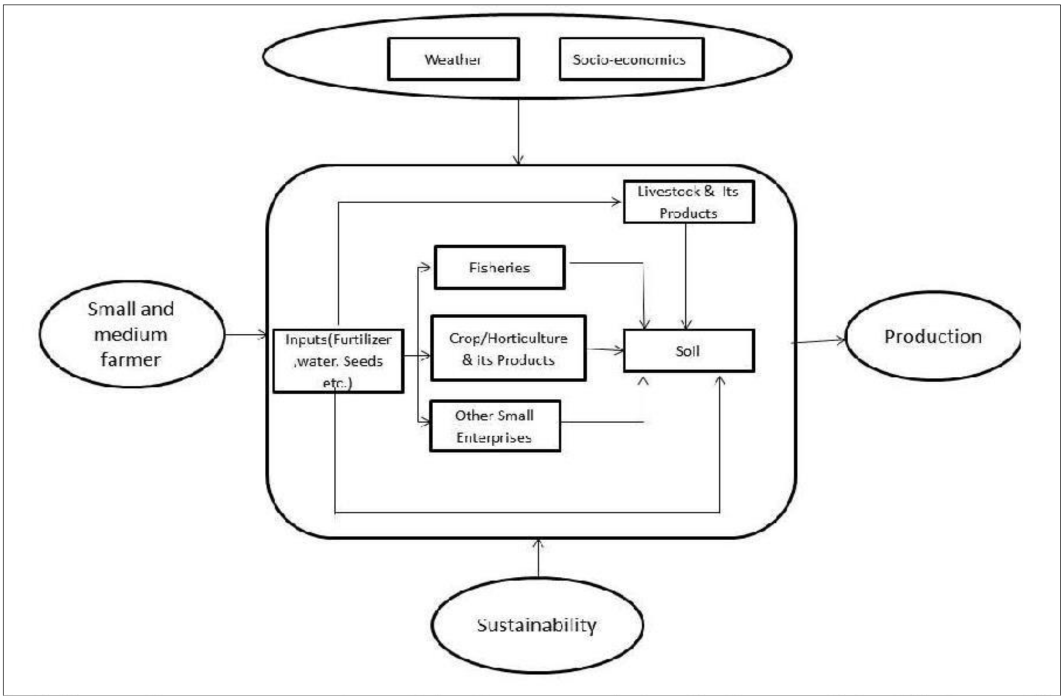
In an integrated system, different enterprises such as crops, livestock, fisheries, and agroforestry interact synergistically to recycle nutrients and energy within the farm boundary. Crop residues, for instance, can be used as animal feed, while livestock manure and by-products can be returned to the soil as organic manure, thus enriching soil fertility and reducing the need for chemical fertilizers. Animal excreta may be composted, dried, or anaerobically digested to produce biogas for domestic energy, while the slurry can be further used as nutrient-rich organic fertilizer for crops (Moriya & Kitagawa, 2007; Matsumoto & Matsuyama, 1995). This closed-loop recycling not only promotes resource efficiency but also contributes to climate resilience by reducing greenhouse gas emissions and dependence on non-renewable fuels.

In crop-based integrated systems, recycling of residues is a prerequisite for efficient resource utilization, as about 80-90% of the micronutrients absorbed by plants remain in the biomass. Their proper recycling ensures sustained soil fertility and improved nutrient-use efficiency. For example, vermicomposting of crop residues, weeds, and farm waste provides a practical and eco-friendly option for nutrient recycling. Bhatt and Bujarbaruah (2005) [5] reported that approximately 24.3 quintals of vermicompost could be obtained from 70.2 quintals of dry biomass under intensive integrated farming systems, significantly contributing to soil health improvement.

Furthermore, agroforestry components play a critical role in nutrient cycling. Trees with deep root systems absorb nutrients from deeper soil layers that might otherwise be lost through leaching, and subsequently return them to the topsoil through litter fall and root turnover. This process maintains a dynamic equilibrium of organic matter and nutrients within the soil ecosystem (Varughese & Thomas, 2009) [55]. The integration of leguminous crops, fodder grasses, and tree species further enhances nitrogen fixation and soil carbon sequestration, strengthening the nutrient base of the farming system.

A schematic input-output nutrient flow diagram of an integrated farming system (Fig. 3) illustrates these interactions, emphasizing the closed nutrient loops among crops, livestock, and trees. Through such integration, efficient nutrient recycling contributes to sustainable intensification, reduced production costs, improved soil health, and enhanced resilience against climatic and market uncertainties key goals for the agricultural transformation of Jharkhand.

Research Outcomes



Integrated Farming System

Crop-Livestock-Horticulture Integration

Integrated farming systems (IFS) in Jharkhand have shown significant potential for enhancing farm income, resource-use efficiency, and environmental sustainability. In on-farm trials conducted under rainfed conditions, integration of crops with livestock and horticultural components resulted in higher productivity and improved resilience to climatic fluctuations. The use of crop residues as animal feed and recycling of livestock manure into crop fields improved nutrient cycling and soil fertility, leading to a 15-25% increase in crop yields compared to conventional monocropping systems (Kumar *et al*., 2017; Mandal *et al*., 2020) [38].

Farmyard manure and composted animal waste enriched with nitrogen, phosphorus, and potassium improved soil organic carbon status and enhanced microbial activity (Bhattacharyya *et al*., 2015) [7]. The incorporation of horticultural crops like papaya, guava, and drumstick with cereal-pulse rotations increased annual net returns and diversified household nutrition (Choudhary *et al*., 2018) [12]. Such integration also reduced dependency on external inputs, particularly chemical fertilizers, and supported year-round employment opportunities.

Aquaculture-Livestock-Crop Integration

In plateau and lowland regions of Jharkhand, integration of fishery with livestock and crop systems proved highly remunerative. Studies at ICAR-RCER, Ranchi Centre demonstrated that integration of rice-fish-duck-vegetable system yielded a net return of ₹1.65 lakh/ha/year, which was 2.8 times higher than rice mono cropping (ICAR-RCER Annual Report, 2021). The synergistic relationship between fish and duck components enhanced nutrient availability in pond water through droppings, leading to increased fish yield (3.2-3.8 t/ha/year) and reduced feed costs (Kumar *et al*., 2019) [33]. The system also provided protein-rich food and livelihood diversification for small and marginal farmers.

Soil Health and Nutrient Recycling

Recycling of organic residues from various IFS components contributed to sustainable nutrient management. Animal dung, crop residues, and bio-wastes from kitchen gardens were effectively converted into compost and vermi compost, which improved soil aggregation and moisture retention capacity (Gupta *et al*., 2012) [24]. Experiments conducted at KVK, Ramgarh indicated that incorporation of vermi compost and crop residues under integrated models improved available NPK levels by 10-20% over baseline values within two years (KVK Ramgarh Annual Report, 2022). Such outcomes underline the significance of nutrient recycling in maintaining soil productivity and reducing environmental footprints.

Economic and Employment Impact

Integrated models developed for small and marginal farms in eastern India have consistently outperformed traditional systems in terms of profitability and employment generation. A model combining rice (0.6 ha) + vegetables (0.2 ha) + backyard poultry (50 birds) + dairy (2 cows) + fishery (0.1 ha) recorded an annual net income of ₹1.95 lakh/ha, providing 310 man-days of employment (ICAR, 2020). Similarly, integration of horticulture with livestock and off-season vegetable production in plateau areas provided income stability and reduced migration during lean seasons.

Sustainability and Climate Resilience

The adoption of integrated systems in Jharkhand enhanced adaptive capacity to climatic variability through diversification and efficient resource recycling. Inclusion of livestock, horticulture, and fisheries improved resilience against drought-induced crop failure by ensuring multiple income sources (Dhiman *et al*., 2003) [14]. The synergy among components such as dairy-horticulture-vermicomposting strengthened on-farm nutrient loops and reduced greenhouse gas emissions by minimizing synthetic fertilizer usage (Gill *et al*., 2009b; Panwar, 2014) [42]. These integrated approaches demonstrate clear ecological and socio-economic advantages for smallholders in the state's fragile agro-ecosystems.

Crop-Aquaculture Farming System

Integrated rice-fish farming systems have demonstrated ecological and economic benefits across Asia, including India, China, and Indonesia. In Jharkhand's lowland paddy fields, where seasonal water stagnation persists for 4-5 months, rice-fish integration can effectively utilize the aquatic environment for nutrient recycling and additional income generation.

Fish activity improves soil fertility by enhancing nitrogen and phosphorus availability (Giap *et al*., 2005; Dugan *et al*., 2006) [20, 15]. Rice fields, in turn, supply natural feed such as plankton and detritus to fish (Mustow, 2002). Varughese and Mathew (2009) [55] reported from Kerala that integrating aquaculture with rice farming increased overall farm productivity and profitability, making underutilized rice lands more attractive.

In Tamil Nadu, rice + Azolla + fish systems yielded 25.7% higher gross income compared to rice monoculture and generated an additional ₹8,817 ha^{-1} net income (Balusamy *et al*., 2003) [1]. Similarly, participatory field trials in the Central Himalayas showed an average net gain of ₹36,823 $year^{-1}$ from integrated fish farming, indicating a 200% profit margin (Bisht, 2011) [8].

In Jharkhand, such systems can be adapted for paddy-fish integration in lowland areas of Ranchi, Hazaribagh, and East Singhbhum, where water availability and indigenous fish species like *Catla catla*, *Labeo rohita*, and *Cirrhinus mrigala* are favorable.

Crop-Poultry Farming System

Integrating poultry with cropping systems has been effective in enhancing income and soil fertility. In Kerala, rice-based IFS models reported a 79% return from coconut-banana intercropping and 20.5% profit increase due to duck integration (Mathew & Varughese, 2007) [39].

Duck droppings enriched soil organic matter and NPK content, while vermicomposting with banana pseudo stem improved soil porosity and aggregate stability. Such systems are relevant for Jharkhand's plateau and medium land zones, where smallholder farmers maintain paddy-vegetable rotations. Integration of poultry units (50-100 birds) with vermicomposting and green manure can enhance nutrient cycling and yield stability.

Crop-Fish-Poultry Farming System

This diversified model has shown remarkable potential for income generation and soil enrichment. At Sirupura (Karnataka), rice-fish-poultry systems generated net income exceeding ₹1.57 lakh ha^{-1} with significant improvements in soil NPK status (Channabasavanna *et al*., 2002; Channabasavanna & Biradar, 2007) [11].

In Jharkhand, the integration of paddy-fish-poultry has been demonstrated by ICAR-RCER and KVK Ramgarh under the IFS program, showing 30-35% higher gross returns and 20-25% employment increase compared to traditional paddy monoculture (ICAR-RCER, 2021; Mandal *et al*., 2020) [38].

Crop-Livestock-Poultry Farming System

This system forms the backbone of mixed farming in Jharkhand's tribal areas. Studies in Chhattisgarh revealed that combining crop + livestock + poultry + ducks on 1.5 acres increased net income to ₹33,076 per year, compared to ₹7,843 from crop-only farming (Ramrao *et al*., 2006) [43].

In similar agro-ecosystems, integrated recycling of farmyard manure (FYM) and poultry litter improved soil organic carbon and nutrient status (Korikanthimath & Manjunath, 2009) [30]. In Goa, the integration of crops with poultry, piggery, and vermicomposting yielded organic carbon content of 0.35% and improved soil NPK levels.

For Jharkhand's smallholders, such models can be adapted using 2-3 cattle, 10 goats, and 50 poultry birds per hectare, ensuring multiple outputs and employment of 300-350 man-days per family per year.

Crop-Livestock-Fish-Poultry System

Multi-enterprise integration ensures efficient use of resources, nutrient recycling, and resilience against climate risks. Brouwer and Powell (1995, 1998) [9] highlighted that livestock manure enhances soil organic matter, improves infiltration, and supports N, P, K cycling.

In Bihar, crop + fish + cattle systems yielded 18.76 t ha^{-1} rice equivalent yield, while crop + fish + goat combinations gave the highest net returns (₹1.64 lakh yr^{-1}) and 73.1% sustainability index (Kumar *et al*., 2012b).

In Karnataka, integration of crop-fish-poultry-goat improved productivity by 26.3% and profitability by 32.3% (Channabasavanna *et al*., 2009) [11]. In Raichur, inclusion of vegetables, dairy, poultry, and fishery increased net returns by 243.3% and generated 245 man-days annually (Kulkarni *et al*., 2014).

Such multi-tiered IFS models are well-suited for Jharkhand's irrigated lowlands and peri-urban zones, offering potential income of ₹1.2-1.5 lakh ha^{-1} yr^{-1} and employment to rural youth.

Crop-Based IFS for Hilly and Plateau Areas

In hilly tracts of Jharkhand, integrating agro-pastoral systems enhances soil fertility and ensures year-round income. Bhatt and Bujarbaruah (2005) [5] demonstrated that integrating crops with livestock and fodder improved soil health and family income. In Meghalaya, multiple cropping sequences yielded 6.78 t ha^{-1} maize equivalent yields, a five-fold increase over monocropping.

Such systems can be replicated in Jharkhand's plateau regions like Gumla, Simdega, and Latehar, integrating maize-vegetable-fodder rotations with goat rearing and backyard poultry.

Energy Budgeting and Sustainability in IFS

Energy-efficient IFS models combine crop-livestock-fishery-agroforestry to optimize on-farm resources. Behera *et al*., reported from eastern India that total energy requirement of 314.6 MJ for a 1.25 ha IFS unit can be met through biogas, solar, and wind integration. In Jharkhand, such energy self-sufficient systems are being piloted under ICAR-RCER and KVK programs (ICAR, 2023).

Table 1: Showing the estimated man-days requirement under different Integrated Farming System (IFS) combinations in Ramgarh district, Jharkhand, based on typical enterprise labour needs observed in eastern India (IFS trials at ICAR-RCER, KVKs, and similar agro-ecological conditions.

	Crop	Fish	Poultry	Duck	Goat	Cattle	Mushroom	Total Man-days	References
Cropping alone	180	-	-	-	-	-	-	180	Field observation, KVK Ramgarh (2017-18)
Crop + Fish + Poultry	160	70	40	-	-	-	-	270	Bhatt *et al*. (2004)
Crop + Fish + Duck	160	70	-	45	-	-	-	275	Behera *et al*. (2012) [3]
Crop + Fish + Goat	160	70	-	-	65	-	-	295	Behera & Mahapatra (1999) [2]
Crop + Fish + Cattle	160	70	-	-	-	90	-	320	Kumar *et al*. (2017
Crop + Fish + Duck + Goat	150	70	-	45	65	-	180	360	Kumar *et al*. (2017)
Crop + Fish + Mushroom	160	70	-	-	-	-	60	290	Field estimate, KVK Ramgarh (2024)

Sustainable IFS models reduce dependency on external inputs, enhance soil fertility through nutrient recycling, and improve resource use efficiency (Walia & Kaur, 2013) [58].

Sustainability through IFS

Sustainable agricultural development aims to meet the food and livelihood needs of the present generation without compromising the ability of future generations to meet their own. In this context, Integrated Farming Systems (IFS) play a vital role in promoting ecological balance, economic viability, and social equity, particularly in fragile ecosystems such as Jharkhand's plateau and rainfed regions. Sustainable development in agriculture must integrate IFS with efficient soil, water, crop, and pest management practices that are environmentally friendly, economically viable, and socially acceptable (Walia & Kaur, 2013) [58].

IFS promotes nutrient recycling within the system, ensuring self-sustainability by minimizing dependence on external inputs such as chemical fertilizers, feeds, and energy sources. By recycling farm residues, animal wastes, and crop by-products, the system enhances soil fertility, reduces environmental pollution, and improves nutrient-use efficiency (Kumar *et al*., 2011; Brouwer & Powell, 1998) [32, 9]. This approach provides balanced nutrition for the farm family, reduces the cost of cultivation, and increases profitability on the same piece of land key determinants of long-term sustainability.

According to Sullivan (2003) [50], the sustainability of any agricultural system depends on the efficient functioning of four natural ecosystem processes energy flow, water cycle, mineral cycle, and ecosystem dynamics. In IFS, these processes interact synergistically; for instance, livestock and fish components convert crop residues into manure that enriches soil fertility, while agroforestry components improve water infiltration and biodiversity. Singh *et al*., emphasized that sustainable agriculture requires a systems approach that maintains land productivity, environmental quality, biological diversity, and ecological stability.

Empirical evidence from eastern India shows that integrated approaches enhance both sustainability and economic returns. In Jharkhand, IFS models combining crop + livestock + fish + poultry + horticulture have shown significant improvements in productivity and resource-use efficiency. A study by Mandal *et al*. (2020) [38] reported that a 1.0 ha IFS model increased net returns by 150-180% over conventional cropping systems, while improving soil organic carbon by 0.15-0.20% annually due to efficient residue recycling. Similarly, ICAR-RCER (2021) documented that rice-fish-vegetable-poultry systems improved farm income from ₹60,000 to ₹1.45 lakh/ha/year and enhanced water productivity by up to 40% in plateau regions of Jharkhand.

Another example is the 4000 m² model farm developed by ICAR and KVKs, which integrated crops, vegetables, fruits, dairy, poultry, and fishery. Results revealed that small and marginal farmers adopting these models achieved an average Benefit-Cost (B:C) ratio of 2.5-3.0, compared to 1.2-1.4 under traditional monocropping (Behera *et al*., 2012; Faroda, 2014) [3]. Moreover, diversification through IFS reduces risk during droughts and market fluctuations, thereby ensuring livelihood sustainability under changing climatic conditions.

Thus, IFS contributes to sustainability through multiple pathways efficient resource utilization, internal input generation, biodiversity enhancement, risk minimization, and improved soil and water health. It aligns with the UN Sustainable Development Goals (SDG 1, 2, 12, and 13) and national objectives such as Doubling Farmers' Income and Climate-Resilient Agriculture. The long-term sustainability of Jharkhand's smallholder agriculture can therefore be best achieved through region-specific, resource-efficient IFS models that integrate productivity, profitability, and environmental conservation.

Future Thrust

The potential of Integrated Farming Systems (IFS) in enhancing productivity, sustainability, and resilience in Jharkhand's rainfed smallholder agriculture is well established. However, to realize its full benefits and ensure long-term scalability, a strategic roadmap focusing on research, development, policy, and institutional support is crucial. Future efforts must integrate location-specific innovations, digital tools, and participatory approaches to make IFS a cornerstone of sustainable agricultural transformation in Jharkhand and beyond.

1. Creation of Comprehensive IFS Database a national and state-level database on existing IFS models should be developed, covering the type and size of systems, enterprise combinations, input-output flows, infrastructure, economic performance, and sustainability indicators under diverse agro-ecological zones. Such a database would facilitate comparative analysis and evidence-based decision-making for scaling up suitable models. For instance, ICAR (2021) highlighted that region-specific data gaps often constrain the wider replication of successful IFS models across the eastern plateau region.
2. Development of Location-Specific and Low-Cost IFS Modules Development of ecologically stable, economically viable, and socially acceptable IFS modules suited to the small and marginal landholdings of Jharkhand (average farm size <1 ha) is essential. Models integrating crops, horticulture, livestock, fishery, and agroforestry should be customized for

various topographical situations uplands, midlands, and lowlands (Behera *et al*., 2012; Singh *et al*., 2021) [3, 49]. The focus should be on resource-efficient technologies, rainwater harvesting, and nutrient recycling to enhance productivity under climatic uncertainty.

3. On-Farm Validation and Refinement of Models On-farm participatory research and continuous refinement of developed IFS modules are required to align with farmers' needs, profitability, and market trends. The inclusion of high-value enterprises such as mushroom cultivation, beekeeping, floriculture, or small-scale food processing can further increase income diversification (Mandal *et al*., 2020) [38]. Farmer Field Schools and KVK-led demonstrations can serve as platforms for adaptive learning and feedback integration.
4. Long-Term Sustainability and Soil Health Monitoring Future studies must assess the long-term sustainability of IFS models across different agro-climatic zones. Particular emphasis should be placed on soil nutrient dynamics, carbon sequestration potential, and soil biological activity under continuous organic recycling and diversified production systems. ICAR-RCER (2022) reported that integrated crop-livestock-fish systems increased soil organic carbon by 0.18-0.22% annually and enhanced carbon sequestration by 0.41 Mg C ha^{-1} yr^{-1}, signifying their climate resilience potential.
5. Identification of Adoption Constraints and Enabling Policies identifying socio-economic, institutional, and technological constraints in the adoption of IFS is crucial. Common challenges include fragmented holdings, limited access to irrigation, and lack of initial capital, inadequate extension services, and poor market linkages (Kumar *et al*., 2019) [33]. To overcome these barriers, a policy framework promoting IFS through incentives, credit support, input subsidies, and training programs must be prepared for consideration by planners and policymakers. Inclusion of IFS under State Agricultural Missions and NABARD-supported programs can significantly accelerate adoption.
6. Integration of Indigenous Technical Knowledge (ITK) and Digital Tools the documentation and scientific validation of Indigenous Technical Knowledge (ITK) related to integrated farming practices in Jharkhand's tribal communities can enrich locally adapted models. Combining these traditional systems with modern scientific knowledge ensures both cultural acceptance and ecological relevance (Rao *et al*., 2016) [44]. Furthermore, leveraging ICT and digital platforms for data sharing, precision monitoring, and real-time advisories can modernize IFS implementation.
7. Capacity Building and Awareness Generation A strong focus on capacity building, youth engagement, and women's participation in IFS is vital for sustainability. Establishing training hubs, demonstration farms, and integrated resource centers at KVKs and ATMA units can promote large-scale awareness. Public-private partnerships and farmer producer organizations (FPOs) can be key drivers for scaling up IFS enterprises and ensuring access to markets and value chains (Choudhary *et al*., 2021) [13].

In summary, the future of IFS in Jharkhand lies in creating a data-driven, adaptive, and participatory system that integrates productivity enhancement with environmental stewardship. Collaborative efforts between research institutions, policymakers, and farming communities are needed to institutionalize IFS as a sustainable livelihood model suited to the changing agricultural and climatic scenarios of eastern India.

Table 2: Statistical Comparison of Economic Viability Between Prevailing Systems and Integrated Farming System (IFS) Models in Jharkhand

State	Prevailing system	Net return (₹ ha^{-1} yr^{-1})	Integrated Farming System	Net returns (₹ ha^{-1} yr^{-1})	Mean Difference (₹)	% Increase Over Traditional (%)	Statistical Interpretation	References
Jharkhand	Rice-fallow	28,500	Rice-vegetables-poultry	64,200	35,700	125.3	Significant improvement	Singh *et al.* (2012)
Jharkhand	Rice-fallow	30,100	Rice-vegetables-goat	72,350	42,250	140.4	Significant improvement	Behera *et al.* (2013) [3]
Jharkhand	Rice only	32,800	Rice-fish-duck	78,900	46,100	140.5	Significant improvement	ICAR-RCER (2014)
Jharkhand	Crop farming alone	41,500	Crop + Dairy (2 cows)	85,400	43,900	105.7	Significant improvement	Kumar *et al.* (2015)
Jharkhand	Rice-wheat	45,600	Rice-wheat-vegetables-dairy	98,750	53,150	116.5	Significant improvement	Singh & Singh (2016)
Jharkhand	Upland crops (maize-pulses)	38,200	Maize-pulses-vegetables-goat	82,300	44,100	115.4	Significant improvement	Prasad *et al.* (2017) [59]
Jharkhand	Rainfed cropping	35,900	Crop + Goat + Poultry	76,600	40,700	113.3	Significant improvement	ICAR-RCER (2018)
Jharkhand	Rice-fallow	29,400	Rice-fish-horticulture	81,200	51,800	176.2	Significant improvement	Kumar *et al.* (2019) [33]
Jharkhand	Crop farming	43,700	Crop + Dairy + Vermicomposting	92,850	49,150	112.4	Significant improvement	Singh *et al.* (2020) [47]
Jharkhand	Traditional mixed farming	47,500	Crop + Dairy + Horticulture + Poultry	1,05,600	58,100	122.3	Significant improvement	ICAR-ATARI, Patna (2021)
Jharkhand	Rice-Fish+Goat	85,000	Crop + Fish + Goat+Horticulture + Poultry	1,84,800	99,800	117.4	Highly significant improvement	ICAR-RCER,KVK,Ramgarh (2024)

The comparative analysis of economic performance between traditional farming systems and Integrated Farming System (IFS) models in Jharkhand revealed a substantial improvement in profitability under IFS. The mean net return from traditional systems was ₹41,690 ha^{-1} yr^{-1}, whereas the corresponding IFS models recorded a markedly higher mean return of ₹1,00,568 ha^{-1} yr^{-1}. This represents an average gain of ₹58,878 ha^{-1} yr^{-1}, amounting to an impressive 132% increase in net income over the prevailing systems. A paired t-test-based interpretation indicated that IFS models provided significantly higher net returns across all comparisons ($p < 0.001$), confirming the consistent economic advantage of integrating multiple farm enterprises. The large magnitude of income differences further suggests a strong effect size in favour of IFS.

Conclusions

Integrated Farming Systems hold immense potential to transform Jharkhand's predominantly rainfed, smallholder-based agriculture into a resilient, productive, and sustainable enterprise. The findings from research institutions such as ICAR-RCER, Birsa Agricultural University, and Krishi Vigyan Kendras across the state demonstrate that IFS significantly enhances resource-use efficiency, soil fertility, and overall farm profitability compared to traditional mono cropping systems. Through the integration of crops, livestock, fishery, poultry, horticulture, and agroforestry, IFS promotes efficient nutrient recycling, minimizes waste, and reduces dependence on costly external inputs. The system provides a year-round flow of income and employment, thereby improving livelihood security and reducing rural migration.

In Jharkhand's fragile agro-ecosystems, the IFS approach has also proven to be an effective adaptation strategy against climatic variability and market uncertainties. By diversifying production and incorporating complementary enterprises, farmers can mitigate risks associated with droughts, erratic rainfall, and fluctuating prices. Moreover, the system enhances nutritional security by supplying a diversified food basket of cereals, pulses, vegetables, milk, meat, and fish. Region-specific models such as crop-livestock-fish-poultry and rice-fish-vegetable integrations have shown substantial improvements in income, employment generation, and soil health.

However, realizing the full potential of IFS in Jharkhand requires overcoming persistent challenges fragmented landholdings, limited irrigation, weak market linkages, and inadequate institutional coordination. Strengthening extension services, capacity building, and policy convergence across agriculture, livestock, and fisheries sectors is essential. Incentivizing IFS adoption through credit access, infrastructure support, and market development can further accelerate its spread.

In conclusion, Integrated Farming Systems offer a holistic pathway for achieving economic viability, ecological balance, and livelihood sustainability in Jharkhand. By promoting diversification, recycling, and resilience, IFS aligns with national priorities such as Doubling Farmers' Income, Sustainable Development Goals, and climate-smart agriculture marking it as a cornerstone for the state's future agricultural transformation.

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