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Mamidala Mahesh

Bharatiya Engineering Science & Technology Innovation University, Gownivaripalli, Gorantla, Sri Sathya Sai, Andhra Pradesh, India

Chittimothu Suresh Babu

Scientist, Department of Soil Science, Institute of Frontier Technology (IFT), Regional Agricultural Research Station, Tirupati, Andhra Pradesh, India

Pinipe Keerthi Priya

Scientist, Department of Soil Science, Institute of Frontier Technology (IFT), Regional Agricultural Research Station, Tirupati, Andhra Pradesh, India

Ch Bhargava Rami Reddy

Scientist, Department of Soil Science, Institute of Frontier Technology (IFT), Regional Agricultural Research Station, Tirupati, Andhra Pradesh, India

Ch Sowmya

Subject Matter Specialist (SMS) Agronomy, Krishi Vigyan Kendra (KVK) - Mamnoon, Warangal, Telangana, India

Ch Naga Jyothi

Scientist (Agronomy), Acharya N. G. Ranga Agricultural University- Regional Agricultural Research Station (RARS), Lam, Guntur, Andhra Pradesh, India

Corresponding Author:

Chittimothu Suresh Babu

Scientist, Department of Soil Science, Institute of Frontier Technology (IFT), Regional Agricultural Research Station, Tirupati, Andhra Pradesh, India

Integrated farming systems for sustainable livelihoods in smallholder agriculture

Mamidala Mahesh, Chittimothu Suresh Babu, Pinipe Keerthi Priya, Ch Bhargava Rami Reddy, Ch Sowmya and Ch Naga Jyothi

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Abstract

Background: Smallholder farmers, who manage farms of 2 hectares or less and constitute over 70% of farmers in developing countries, face an increasingly complex web of challenges: climate variability, market volatility, declining soil fertility, limited capital access, and food and nutritional insecurity. Integrated Farming Systems (IFS)-characterized by the deliberate combination of crop production, livestock rearing, aquaculture, horticulture, agro-processing, and agroforestry components within a single farm enterprise-have emerged as a scientifically validated approach to overcoming these challenges by generating synergies among farm components and recycling resources efficiently.

Methods: This review critically synthesizes evidence from over 200 peer-reviewed studies, ICAR network program reports, FAO assessments, and CGIAR research outputs spanning 1985–2024, covering the design, performance, economic outcomes, and sustainability of IFS models across smallholder agricultural contexts in South Asia, Southeast Asia, East Africa, and West Africa.

Results: Documented IFS models demonstrate 25–65% higher farm income compared to monoculture or single enterprise systems, with marked improvements in household food security (35–55% increase in dietary diversity scores), resource use efficiency (30–50% reduction in external input requirements), and environmental sustainability (soil organic carbon gains of 0.2–0.8 t ha⁻¹ year⁻¹). Gender-responsive IFS designs incorporating women-led enterprises show additional nutritional and social empowerment outcomes.

Conclusions: IFS represents a transformative pathway to sustainable smallholder livelihoods when supported by appropriate policy, extension, credit, and market linkage frameworks. Its mainstreaming requires context-specific design, participatory technology development, and systems-level evaluation beyond component-level crop yields

Keywords: Integrated farming systems, smallholder agriculture, sustainable livelihoods, diversified farming, crop-livestock integration, agroforestry, resource use efficiency, food security

1. Introduction

Smallholder agriculture-defined by FAO as farming on landholdings of 2 hectares or less-is the backbone of food production in developing countries. The global smallholder sector encompasses an estimated 500 million farms worldwide, employing over 1.5 billion people and producing 70–80% of food consumed in Africa and Asia (Ricciardi *et al.*, 2018) ^[21]. Despite their numerical dominance and critical role in feeding the world, smallholder farmers are disproportionately represented among the food insecure and poor: over 60% of the world's chronically food insecure live in smallholder farming households. This paradox-farmers who grow food yet remain hungry-reflects structural constraints including limited land, capital, market access, and institutional support, compounded by growing environmental and climatic stresses.

The dominant paradigm of conventional agricultural development-specialization, intensification, and market integration-has delivered productivity gains for farmers with resources and market access but has frequently bypassed or harmed the most marginalized smallholders. Single-crop specialization in cash crops (cotton, tobacco, sugarcane) has increased income in good years but left farm households vulnerable to price crashes, pest

outbreaks, and erratic weather. Green Revolution technologies, while transformative in irrigated systems, have generated dependencies on purchased inputs that burden smallholders with debt and erode soil health through monoculture and chemical overuse (Pingali, 2012) ^[17].

In this context, Integrated Farming Systems (IFS)-also referred to as integrated crop-livestock systems (ICLS), integrated rural development systems, or farm systems-have attracted growing scientific and policy attention as a holistic approach to smallholder agricultural development. The IFS concept is grounded in the agroecological principle that farm systems composed of multiple, biologically and economically complementary components generate synergies that cannot be achieved by optimizing each component in isolation. Crops provide feed, residues, and organic matter for livestock; livestock provide manure, draft power, and income for crop production; aquaculture ponds receive crop residues and animal waste and produce fish and nutrient-rich water for field irrigation; trees provide shade, fodder, timber, and fuel while fixing nitrogen and improving microclimates. The whole, in IFS, is greater than the sum of its parts.

India has a long tradition of integrated farming, with ancient agricultural texts-including the Arthashastra (c. 321 BCE)-describing multi-component farming systems that integrated crops, animals, ponds, and trees. Modern scientific interest in IFS began with the establishment of the All India Coordinated Research Project on Integrated Farming Systems (AICRP-IFS) by the Indian Council of Agricultural Research (ICAR) in 1974, which generated decades of systematic research on IFS performance across diverse agro-ecological and socioeconomic contexts. Internationally, the CGIAR Research Program on Crop-Livestock-Water Interactions and FAO's Save and Grow initiative have championed IFS as a pathway to sustainable intensification.

This review aims to synthesize the current state of knowledge on integrated farming systems with specific reference to their design principles, component interactions, economic and livelihood outcomes, environmental sustainability, and scaling pathways. The review draws on evidence from major IFS research programs in India, South and Southeast Asia, sub-Saharan Africa, and Latin America to provide a

comprehensive, critical analysis of IFS potential for transforming smallholder agriculture in the 21st century.

2. Conceptual framework of integrated farming systems

2.1 Definition and Scope

Integrated Farming System (IFS) is defined as a diversified farm enterprise that combines crop production, animal husbandry, aquaculture, agro-forestry, and/or post-harvest agro-processing components in a cohesive system where wastes from one component serve as inputs to another, optimizing resource use efficiency, productivity, income stability, and environmental sustainability on a unit land area (Rangasamy *et al.*, 2006) ^[19]. This definition encompasses several important features that distinguish IFS from simple multi-cropping or mixed farming: (i) the emphasis on functional integration-not mere juxtaposition-of components; (ii) the circular use of farm-derived resources (manure, crop residues, slurry, pond water); (iii) the explicit optimization of system-level outcomes including income stability, food security, and environmental performance; and (iv) the unit of analysis as the whole farm system rather than individual crops or components.

IFS is conceptually underpinned by the principles of agroecology: ecological processes (nutrient cycling, biological control, soil biology) are harnessed to reduce external inputs while maintaining or enhancing productivity. IFS is a form of ecological intensification-producing more food and income per unit of land, water, and input through biological synergies rather than through increased application of chemical inputs. This aligns IFS with the sustainability transition required by global agri-food systems in the context of climate change, resource depletion, and environmental degradation.

2.2 Typology of IFS Models

IFS models are highly diverse, reflecting the ecological, social, cultural, and market contexts of different farming communities. A useful typological framework classifies IFS by the nature and number of integrated components. Table 1 summarizes major IFS typologies, their key components, agro-ecological suitability, and primary outcomes.

Table 1: Typology of Integrated Farming System models: components, suitability, and outcomes

IFS Type	Key Components	Agro-Ecological Zone	Primary Outcomes	Key Example Regions
Crop-Livestock IFS	Cereals/legumes + dairy/beef cattle/buffalo/goat	Humid-semi-arid	Manure, draft power, income stability	Indo-Gangetic Plain, East Africa
Crop-Poultry IFS	Crops + layer/broiler poultry	Humid/sub-humid	Egg/meat production, manure utilization	South/SE Asia, West Africa
Rice-Fish IFS	Rice + fish culture in paddies	Humid rice zones	Protein, pest control, income	SE Asia, NE India, Bangladesh
Crop-Livestock-Fish IFS	Crops + animals + pond aquaculture	Humid/sub-humid	Diversified income, nutrition security	South/SE Asia, China
Agroforestry-Crop IFS	Trees + annual/perennial crops	All zones	Soil health, C sequestration, fodder	Africa, India, SE Asia
Crop-Biogas-Vermicompost IFS	Crops + cattle + biogas + vermicompost	Semi-arid/humid	Energy, organic fertilizer, income	India, China, Nepal
Horticulture-Livestock IFS	Vegetables/fruit + goat/poultry	All zones	Income diversification, nutrition	India, Bangladesh, Philippines
Integrated Village-Level IFS	Multi-component community-scale system	All zones	Village food/nutrition security	India (ICAR models), Philippines

Source: Author's compilation from ICAR-AICRP-IFS (2018) ^[11], Dixon *et al.* (2001) ^[6], and Devendra and Thomas (2002) ^[5]

2.3 Theoretical Underpinnings: Systems Thinking and Agroecology

IFS is grounded in systems thinking-an approach that

recognizes the farm as a complex adaptive system with emergent properties arising from interactions among components. Systems thinking in agriculture was pioneered

by Howard Odum, David Pimentel, and Conway and Barbier (1990) ^[4], who developed frameworks for analyzing agricultural system performance across multiple dimensions: productivity, stability, sustainability, equitability, and autonomy. These five properties—the 'PSSEA' framework—remain relevant benchmarks for evaluating IFS.

Agroecological principles provide the scientific foundation for IFS design. The principle of diversity is central: greater compositional diversity in crop and animal species on a farm correlates with greater functional diversity—the range of ecological processes performed—leading to higher system resilience and stability. The principle of nutrient cycling—closing nutrient loops through organic matter recycling and biological nitrogen fixation—is operationalized in IFS through manure management, composting, biogas-slurry return, and legume integration. The principle of synergy—where component interactions produce outputs greater than the sum of inputs—is the core value proposition of IFS and distinguishes it from simple diversification.

3. Major ifs components and their interactions

3.1 Crop Production Component

The crop component forms the foundation of most IFS models, providing food grains, fodder, raw materials for agro-processing, and organic matter for recycling to other components. In South Asian IFS models, the crop component typically consists of a kharif (rainy season) cereal (rice, maize, sorghum, or pearl millet) and a rabi (winter season) crop (wheat, chickpea, mustard, or safflower), often complemented by a zaid (summer) vegetable or fodder crop. This sequential three-season cropping pattern maximizes cropping intensity (250–350%) and land use efficiency. The choice of crops in IFS is guided not only by market value and human food requirements but also by their functional role within the integrated system. Leguminous crops—pulses, oilseeds, and fodder legumes—are strategically integrated for their nitrogen fixation function, reducing the system's dependence on mineral N fertilizers. Fodder crops (maize, sorghum, lucerne, berseem) are included to supply year-round green fodder for the livestock component. Horticulture crops (vegetables, fruits) provide high-value income, nutritional diversity, and often serve as inputs for farm-level processing (pickles, dried vegetables, juices).

3.2 Livestock Component

The livestock component is the central integrating hub of most IFS models, converting crop residues and fodder into manure, draft power, milk, meat, eggs, and income. Cattle—particularly cross-bred dairy cows—are the dominant livestock component in IFS models in South Asia, providing both milk income and manure for composting or biogas production. In smallholder contexts, the decision to maintain dairy animals is closely related to the availability of crop residue (straw) as dry-season roughage, creating a direct functional link between crop and livestock components.

Goat and sheep rearing is a particularly important IFS component for marginal and small farmers, given the modest capital investment required, short breeding cycle, and dual function as both income source and manure producer. Studies from Andhra Pradesh and Karnataka document that goat-integrated smallholder systems generate net returns of INR 15,000–25,000 per adult animal per year from milk, offspring sales, and manure value, substantially diversifying farm income and reducing dependence on crop production alone (Devendra and Thomas, 2002) ^[5].

Poultry integration—particularly backyard layer or broiler production—is one of the most accessible and rapidly replicable IFS components for smallholder households. Layer poultry units of 20–50 birds can generate INR 25,000–40,000 per year in egg sales at modest capital investment and minimal land footprint, while poultry litter (a rich source of N, P, K, and micronutrients) supplements crop nutrition. In rice-fish-poultry integrated systems studied in West Bengal and Andhra Pradesh, poultry droppings falling into ponds stimulated plankton growth that served as natural fish feed, effectively closing the nutrient loop and reducing purchased fish feed requirements by 30–40% (Jana, 1998) ^[9].

3.3 Aquaculture Component

Fish culture in farm ponds is an IFS component of enormous importance in humid and sub-humid tropical regions, where small water bodies can be established at modest cost. Farm ponds serve multiple functions: fish production, domestic water supply, irrigation water storage, and nutrient recycling from crop and animal waste inputs. The integration of aquaculture into IFS models has been most comprehensively developed in South and Southeast Asia, where rice-fish, polyculture pond, and cage aquaculture systems have been rigorously studied.

In composite fish culture—the dominant pond aquaculture model in Indian IFS—a mixture of carps (Indian major carps: rohu, catla, mrigal; and exotic carps: silver carp, grass carp, common carp) is stocked at a total density of 5,000–8,000 fingerlings ha⁻¹ to exploit different feeding niches in the water column, maximizing pond productivity without external feed inputs. Under integrated management—where crop residues, cattle dung, and poultry litter are applied as pond inputs—composite fish culture yields of 3,000–6,000 kg ha⁻¹ year⁻¹ are achievable without commercial feed, representing protein production of exceptional efficiency per unit area (MPEDA, 2022) ^[12].

3.4 Agroforestry Component

The integration of trees and shrubs with crops and livestock—agroforestry—adds an important temporal and spatial dimension to IFS by providing products and services that span multiple years and occupy vertical strata not used by annual crops. Multipurpose tree species (MPTS) such as *Leucaena leucocephala*, *Sesbania grandiflora*, *Moringa oleifera*, *Gliricidia sepium*, and *Tithonia diversifolia* are commonly integrated in IFS systems for their combination of fast growth, nitrogen fixation, high-quality leaf protein fodder, shade provision, and biomass for organic matter.

Moringa oleifera, the drumstick tree, deserves special mention as an IFS component of extraordinary versatility. Its leaves—containing 27% protein, abundant beta-carotene, iron, and calcium—serve as human food, livestock fodder, and a source of bioactive compounds with medicinal properties. *Moringa* leaf powder has been documented to improve milk yield in dairy cattle by 12–18% when fed at 2–3% of dietary dry matter (Mendieta-Araica *et al.*, 2011) ^[11]. The pods are consumed as vegetables with high market value in South India, providing significant cash income for smallholder IFS practitioners in Andhra Pradesh, Tamil Nadu, and Karnataka.

Coconut-based IFS in coastal and humid regions of South and Southeast Asia represent highly developed examples of multi-story agroforestry IFS. In Kerala and coastal Andhra Pradesh, the coconut-banana-vegetable-poultry-fish system integrates 4–5 agricultural enterprises under the coconut canopy, achieving remarkably high annual gross income per unit area

(INR 120,000–200,000 ha⁻¹) while maintaining soil health and biodiversity (Nair, 2012)^[14].

3.5 Agro-processing Component

Value addition through on-farm or village-level processing of agricultural produce is increasingly recognized as a critical IFS component for enhancing income, reducing post-harvest losses, and creating year-round employment. In IFS models with strong dairying components, processing milk into curd, ghee, paneer, or butter adds substantial value—50–100% premium over raw milk—and extends shelf life, reducing perishability losses. Village-level dairy cooperatives (e.g., under the Amul model in Gujarat) have demonstrated that organized processing and marketing of dairy products from IFS farms can generate stable livelihoods for thousands of smallholder families.

Similarly, processing of millet, spices, and vegetables through community-level mills, driers, and packaging facilities has been documented to generate 30–50% higher household income compared to selling raw produce (NABARD, 2020)^[13]. The development of certified organic IFS products commanding premium prices in niche markets—organic rice, millet flours, organic turmeric, and herbal products—represents a growing opportunity for value-added IFS in India.

4. ICAR Models of integrated farming systems

4.1 ICAR-AICRP-IFS Network

The All India Coordinated Research Project on Integrated

Farming Systems (AICRP-IFS), established in 1974 and currently coordinated by ICAR-IARI (Indian Agricultural Research Institute), represents the world's most extensive national network for IFS research. The AICRP-IFS operates across 26 centers covering all major agro-ecological zones of India—from the Indo-Gangetic alluvial plains to the rainfed Deccan Plateau, the coastal deltaic zones, the humid northeast, and the arid northwest—enabling evaluation of IFS models under diverse agroecological and socioeconomic conditions.

The fundamental approach of AICRP-IFS is to design IFS models for specific land and resource endowments—typically 1 hectare for a 4–5 member farm family with defined capital and labor availability and compare their performance against conventional single-enterprise systems (rice monoculture, wheat monoculture, or cotton sole crop) across multiple years. The evidence generated by this network over five decades constitutes the most robust dataset for IFS performance evaluation in a developing country context.

4.2 Representative ICAR IFS Models and Performance

AICRP-IFS research has developed and validated dozens of IFS models tailored to specific agro-ecological zones and resource endowments. Table 2 presents key validated IFS models from representative centers and their documented performance outcomes.

Table 2: ICAR-AICRP-IFS validated models: design, productivity, and income outcomes (1-ha farm basis)

Center / Zone	IFS Model Components	Annual Income (INR/ha)	% Over Control	Employment (Days/ha/yr)	Key Reference
Modipuram (UP) / IGP	Rice+Wheat+Fodder+Dairy+Poultry+Fish	1,82,500	+72	485	AICRP-IFS (2018) ^[1]
Coimbatore (TN) / Semi-arid	Cotton+Sorghum+Groundnut+Sheep+Vegetable	1,45,000	+65	420	Rangasamy <i>et al.</i> (2006) ^[19]
Bhubaneswar (Odisha) / Humid	Rice+Fish+Vegetable+Mushroom+Dairy	1,62,000	+58	465	Panda <i>et al.</i> (2013) ^[15]
Ludhiana (Punjab) / IGP	Rice+Wheat+Dairy+Mushroom+Beekeeping	2,10,000	+68	510	Bhatt <i>et al.</i> (2016) ^[2]
Hyderabad (AP/TS) / Semi-arid	Sorghum+Pigeon pea+Cotton+Sheep+Poultry	1,38,000	+55	395	Reddy <i>et al.</i> (2019) ^[20]
Imphal (Manipur) / Humid	Rice+Fish+Vegetables+Pig+Duck	1,25,000	+60	440	Sharma <i>et al.</i> (2017) ^[23]
Navsari (Gujarat) / Coastal	Sugarcane+Banana+Vegetables+Dairy+Poultry	2,35,000	+70	530	Patel <i>et al.</i> (2018) ^[16]
Barrackpore (WB) / Humid alluvial	Rice+Jute+Vegetables+Fish+Duck+Mushroom	1,55,000	+62	475	Jana <i>et al.</i> (2020) ^[10]

Source: ICAR-AICRP-IFS Annual Reports (2014–2022); NFBSFARA Technical Bulletin (2020)

The data in Table 2 consistently demonstrate that ICAR IFS models generate 55–72% higher annual farm income compared to conventional monoculture or dual-enterprise systems on the same unit area. Employment generation—averaging 420–530 person-days per hectare per year—is substantially higher than that of crop monoculture (150–250 person-days ha⁻¹ year⁻¹), indicating IFS as a potent strategy for rural employment generation and labor absorption.

The Coimbatore model deserves detailed attention as a paradigm for semi-arid dryland IFS in peninsular India. Developed at TNAU Coimbatore for 1-ha smallholder farms with limited irrigation, the model integrates cotton (0.4 ha), sorghum (0.2 ha), groundnut (0.2 ha), vegetable garden (0.05 ha), and sheep rearing (5 ewes + 1 ram) on 0.15 ha fodder plot. System-level outcomes include: annual gross income of INR 145,000 compared to INR 88,000 for cotton sole crop; food self-sufficiency achieved for cereals, pulses, and vegetables; 42% reduction in household expenditure on food; and 2.1 t ha⁻¹ organic carbon increment after 5 years due to manure recycling.

4.3 Coconut-Based IFS Models in Coastal India

Coconut-based IFS, developed and promoted by ICAR-CPCRI (Central Plantation Crops Research Institute, Kasaragod), exemplifies multi-story IFS under plantation crops. Coconut gardens in Kerala, coastal Karnataka, and coastal Andhra Pradesh can support a diverse range of intercrops and livestock components under the coconut canopy. The CPCRI-developed model integrates coconut + banana + vegetable/tuber crops in the canopy, with poultry (layer hens), dairy goats, and vermicompost units generating additional income while recycling farm wastes. Income from this system on 1 ha was documented at INR 180,000–220,000 per year, compared to INR 80,000–100,000 from coconut sole crop, with the added benefit of reduced input dependence through organic cycling.

5. Resource use efficiency in ifs

5.1 Land Use Efficiency

Land use efficiency in IFS is quantified through the System Productivity Index (SPI) a measure that converts all IFS

component outputs to rice-equivalent yield for cross-system comparison and through the Cropping Intensity Index. AICRP-IFS studies consistently demonstrate SPIs of 5,000–8,500 kg rice equivalent ha⁻¹ year⁻¹ for IFS models compared to 3,500–5,000 kg ha⁻¹ for rice-wheat monoculture systems and 2,500–3,500 kg ha⁻¹ for dryland cereal monocultures. This 30–60% superiority in land use efficiency reflects the exploitation of year-round growing seasons, vertical space (through agroforestry), and complementary niches among components.

Cropping intensity in IFS models reaches 300–350%, meaning the land is under productive use year-round across three or more crop seasons or enterprises simultaneously, compared to 150–200% cropping intensity in conventional double-crop systems. The integration of perennial components (trees, banana, tubers) further increases the temporal continuity of land use, generating outputs even in off-season periods.

5.2 Water Use Efficiency

Water use efficiency is enhanced in IFS through several mechanisms: (i) diversification of crop and enterprise types with different seasonal water demand peaks, reducing peak demand conflicts; (ii) recycling of pond water, biogas effluent, and wastewater from processing units for crop irrigation; (iii) conservation tillage and mulching that reduce soil evaporation; and (iv) deep-rooted perennial trees that access water from deeper soil horizons unused by annual crops.

Studies on IFS models in canal command areas of Andhra Pradesh and Karnataka have demonstrated that IFS adopts achieve 20–30% higher crop water productivity (kg grain per m³ water applied) compared to conventional monoculture irrigators, owing to diversification of water use across crops with different peak demand times and the use of recycled water from ponds and biogas effluent for supplemental irrigation. In tank-fed IFS models in Karnataka, fish pond water recycled for vegetable irrigation reduced irrigation water needs by 35–45% and improved vegetable yields by 20–25% through higher nutrient content of pond water.

5.3 Nutrient Use Efficiency

Nutrient cycling is the most distinctive and economically significant dimension of IFS resource use efficiency. The manure–compost–biogas slurry loop where crop residues and fodder feed livestock, livestock manure is converted to biogas

(energy) and slurry (nutrient-rich organic fertilizer), and slurry is returned to crops substantially reduces external fertilizer requirements. Studies at multiple AICRP-IFS centers demonstrate that IFS models using full organic recycling of farm wastes (manure, crop residue, fish pond sludge) meet 60–80% of crop N requirements internally, reducing chemical N fertilizer demand by 40–60 kg N ha⁻¹ season⁻¹ compared to monoculture controls.

Nitrogen Use Efficiency (NUE) the fraction of applied N that is recovered in harvested products is significantly higher in IFS (40–60%) than in fertilizer-intensive monoculture systems (25–40%), owing to the distribution of N across multiple crops and enterprises with different uptake kinetics and the organic form of N supply through composted manures, which reduces leaching losses. Biogas slurry - the liquid effluent from biogas digesters - has been shown to contain nearly all the original N in ammoniacal form available for immediate plant uptake, combined with stable humic substances that improve soil water holding capacity (Sathish *et al.*, 2019)^[22].

6. Food and nutritional security

6.1 Dietary Diversity and Nutritional Outcomes

One of the most compelling arguments for IFS in smallholder contexts is its direct contribution to household food and nutritional security through production of a diverse range of foods on a single farm. IFS farms producing cereals, pulses, vegetables, fruits, milk, eggs, and fish provide the full spectrum of macronutrients (carbohydrates, protein, fat) and micronutrients (iron, zinc, calcium, vitamins A, B, C) required for a balanced diet, reducing dependence on purchased food and market access for nutrition. This 'farm-to-plate' nutritional pathway is particularly important for households in remote rural areas with limited market access.

Household Dietary Diversity Score (HDDS)-a validated proxy indicator of nutritional adequacy-has been measured in multiple IFS adoption studies. A comprehensive evaluation of IFS models across 500 smallholder households in Karnataka, Andhra Pradesh, and Odisha by ICAR-IIMR (2020)^[8] documented that IFS-adopting households had HDDS scores of 8.2–9.1 (out of 12 food groups) compared to 5.3–6.4 for non-IFS households in the same villages, indicating substantially superior dietary diversity. Child stunting rates-a measure of chronic malnutrition were 28–35% lower among IFS-adopting households compared to matched controls in this study.

Table 3: Nutritional security indicators in IFS vs. non-IFS smallholder households: evidence from India

Indicator	IFS Households	Non-IFS Households	% Improvement	Source
Household Dietary Diversity Score	8.2–9.1	5.3–6.4	+45–65%	ICAR-IIMR (2020) ^[8]
Food Self-sufficiency (months/year)	9–11	5–7	+50–70%	Panda <i>et al.</i> (2013) ^[15]
Protein intake (g/day/person)	62–75	38–48	+55–65%	Bhatt <i>et al.</i> (2016) ^[2]
Animal protein intake (g/day/person)	22–32	8–14	+150–180%	AICRP-IFS (2018) ^[1]
Iron intake adequacy (%)	72–85	42–58	+45–65%	Reddy <i>et al.</i> (2019) ^[20]
Calcium intake adequacy (%)	68–80	38–52	+60–75%	Sharma <i>et al.</i> (2017) ^[23]
Child stunting rate (%)	18–24	32–42	-40–50%	ICAR-IIMR (2020) ^[8]
Vegetable consumption (g/day)	185–240	85–120	+95–115%	Patel <i>et al.</i> (2018) ^[16]

Source: Compiled from AICRP-IFS Annual Reports (2018–2022) and cited literature

6.2 IFS and Gender-Differentiated Food Security

IFS outcomes are significantly mediated by gender dynamics within farm households. Women in smallholder IFS households are typically the primary managers of homestead gardens, poultry, small ruminants, and vegetable production - the components most directly linked to household nutritional

security and women's income control. Evidence consistently shows that women's control over IFS component income-particularly from poultry and vegetable sales-is positively associated with better child nutritional outcomes, higher food expenditure allocation, and higher rates of school enrollment for daughters (Quisumbing *et al.*, 2014)^[18].

Gender-responsive IFS design—ensuring that women have decision-making authority over components they manage, that labor burdens are considered in enterprise selection, and that women have access to IFS training and extension—significantly amplifies nutritional and livelihood outcomes. IFS programs in Andhra Pradesh that deliberately targeted women's self-help groups (SHGs) as the primary IFS training unit and provided capital subsidies for women's enterprise components documented 25–40% greater improvement in HDDS and household income compared to programs targeting male household heads alone.

7. Environmental sustainability of IFS

7.1 Soil Health

Soil health improvement is one of the most consistently documented benefits of IFS compared to monoculture or conventional farming systems. The combination of diverse crop rotations, organic matter inputs from livestock manure and crop residues, and reduced tillage under IFS significantly improves soil physical, chemical, and biological properties. Long-term (10–15 year) IFS trials at AICRP-IFS centers have documented increases in soil organic carbon (SOC) of 0.2–0.8 t C ha⁻¹ year⁻¹ compared to annual SOC losses of 0.1–0.3 t C ha⁻¹ year⁻¹ under monoculture intensive cultivation.

Soil biological indicators—microbial biomass carbon (MBC), dehydrogenase activity, earthworm population density—are significantly higher under IFS than monoculture. Long-term IFS plots at Modipuram showed 2.5–3.0× higher MBC compared to rice-wheat monoculture after 12 years, reflecting the positive impact of organic inputs, crop diversity, and reduced pesticide use on soil microbial communities. Earthworm populations—sensitive indicators of soil health and key contributors to soil structure and nutrient availability—were 3–5× higher in IFS compared to monoculture plots at multiple AICRP centers.

7.2 Biodiversity Conservation

IFS landscapes support substantially higher biodiversity at multiple scales compared to monoculture farming landscapes. On-farm species diversity—of crops, trees, livestock breeds, and associated flora and fauna—is intrinsically higher in IFS. Farm-level biodiversity assessments in IFS systems in Kerala, Karnataka, and Odisha have documented 8–15 crop species, 3–6 tree species, 2–4 livestock species, and 40–80 associated plant species on farms of 1–2 ha, compared to 1–3 crop species and 10–25 associated plants on comparable monoculture farms.

The ecological network of IFS—where multiple crops, trees, water bodies, and animals interact across space and time—creates diverse structural niches for wildlife. Studies in Kerala's coconut-based IFS landscapes found 2–3× higher bird species richness and 1.5–2× higher arthropod diversity compared to oil palm monoculture landscapes in the same region, with direct implications for biological pest control and pollination services that reduce the need for chemical inputs.

7.3 Greenhouse Gas Emissions and Carbon Footprint

Life Cycle Assessment (LCA) studies comparing IFS with monoculture systems in India have documented significantly lower greenhouse gas (GHG) emission intensities for IFS. A comprehensive LCA study of rice-based IFS versus rice-wheat monoculture in the Indo-Gangetic Plain by Chauhan *et al.* (2019) [3] found that IFS emitted 1.8–2.3 t CO₂ equivalent ha⁻¹ year⁻¹ less than monoculture, while producing 55–70% more food per hectare. The GHG emission intensity (kg CO₂-

eq kg⁻¹ food produced) was 40–55% lower in IFS due to reduced synthetic fertilizer use, organic carbon sequestration, and methane avoidance through improved manure management.

Biogas integration into IFS offers additional GHG benefits: methane captured from livestock manure digestion (rather than released as fugitive emissions) generates clean cooking energy while producing biogas slurry that replaces synthetic N fertilizer, with avoided N₂O emissions from mineral fertilizer application. Studies in Gujarat estimate that a 1-ha IFS with a 2 m³ biogas plant fed by cattle dung reduces household CO₂ equivalent emissions by 2.5–3.5 t year⁻¹ compared to conventional fuel and fertilizer use, representing significant climate mitigation at scale.

8. Economic analysis of IFS

8.1 Income and Profitability

The economic performance of IFS relative to conventional farming is documented across diverse agro-ecological and market contexts in India and globally. Comparative economic analyses from AICRP-IFS centers consistently demonstrate net income advantages of 40–75% for IFS over monoculture or dual-enterprise conventional systems on the same land area (Table 2). The income advantage arises from multiple streams: (i) higher total productivity per unit area through component synergies; (ii) income diversification reducing the probability of total income collapse in any year; (iii) reduced external input costs through organic recycling; and (iv) value addition through on-farm processing.

Benefit-cost ratio (BCR) analysis across AICRP-IFS centers shows BCRs of 1.8–2.8 for IFS models compared to 1.2–1.8 for monoculture controls, with the higher BCRs reflecting both higher gross income and lower input costs per rupee invested. Risk-adjusted return analysis—critical for resource-poor smallholders—shows even greater advantages for IFS: the coefficient of variation in annual net income is 35–55% lower in IFS households than in monoculture households, reflecting the stabilizing effect of enterprise diversification on income volatility.

8.2 Employment Generation

One of the most policy-relevant outcomes of IFS is its capacity to generate rural employment. AICRP-IFS studies document 380–530 person-days ha⁻¹ year⁻¹ of employment in IFS models, compared to 150–250 person-days for rice-wheat monoculture and 180–280 person-days for other conventional double-crop systems. This 60–120% higher employment generation per unit area has profound implications for rural poverty reduction, particularly in states with high unemployment and out-migration pressure.

The quality of employment generated by IFS is also superior: livestock management, fish harvesting, processing, and marketing activities generate year-round employment distributed more evenly across seasons compared to the highly seasonal employment of monoculture cropping. The self-employment generated by IFS—estimated at 280–380 days per family per year—reduces dependence on agricultural wage labor markets that are seasonal, volatile, and increasingly scarce as farm mechanization advances.

8.3 Capital Requirements and Adoption Barriers

While IFS demonstrates compelling economic advantages, adoption by smallholders is constrained by upfront capital requirements for establishing livestock, pond, processing, or agroforestry components. The capital investment required for

a full ICAR IFS model on 1 ha ranges from INR 40,000 to 150,000 depending on component choice, representing a significant barrier for marginal farmers with limited savings or credit access. Livestock component establishment-purchasing cross-bred cows, goats, or a layer poultry unit-accounts for the largest share of IFS establishment costs.

Financial services innovations addressing this barrier include: NABARD's Integrated Development Programme for farmers transitioning to IFS; state government subsidy schemes for IFS components (up to 50% subsidy for dairy animals, poultry units, and biogas plants in several Indian states); SHG-linked credit for women's enterprise components; and insurance products for IFS enterprises (crop, livestock, and aquaculture insurance bundled as IFS enterprise insurance). Evidence from Andhra Pradesh's IFS promotion programs shows that when capital constraints are addressed through targeted credit and subsidy schemes, IFS adoption rates among marginal and small farmers can reach 60–75% within 3–5 years of program initiation.

9. Climate change resilience of IFS

9.1 IFS as a Climate Adaptation Strategy

The multi-component structure of IFS provides an intrinsic buffer against climate-induced production variability. When drought reduces cereal yields, livestock (fed on crop residues and stored fodder) continue to generate income through milk, meat, and offspring sales. When flooding disrupts field crop production, fish ponds may experience enhanced productivity from nutrient loading. When market prices for one commodity crash, other IFS enterprises insulate household income. This portfolio diversification—an agricultural analog of financial portfolio theory—is the primary mechanism through which IFS delivers climate resilience.

Quantitative evidence of IFS climate resilience comes from longitudinal farm surveys that span years of normal and abnormal weather. A 10-year panel study of 240 smallholder farms in semi-arid Andhra Pradesh by Gadge *et al.* (2021)^[7] found that IFS households experienced 38% lower interannual income variability than monoculture households over the study period, with the greatest divergence occurring in drought years—confirming the resilience function of IFS enterprise diversification under climate stress. In the drought year of 2018, IFS households maintained 72% of their normal income (from livestock, poultry, and horticultural components) while monoculture households experienced 55% income collapse due to complete sorghum crop failure.

9.2 Agroforestry as a Climate Resilience Tool

Agroforestry components within IFS play multiple climate adaptation functions: (1) tree canopy shading reduces air and soil temperatures under the tree canopy by 2–4°C, attenuating heat stress on understory crops and livestock; (2) deep tree roots access subsoil water and bring nutrients from deeper layers, supporting understory crops during drought; (3) tree windbreaks reduce wind erosion and crop lodging during storm events; and (4) tree biomass and roots contribute significantly to farm carbon sequestration, with estimates of 1–3 t C ha⁻¹ year⁻¹ in agroforestry-integrated IFS.

Parkland agroforestry—the retention of scattered multipurpose trees in crop fields—is the dominant traditional IFS-agroforestry combination across the West African Sahel and parts of India. Research in Niger and Burkina Faso has documented that sorghum and pearl millet yields under the canopy of *Faidherbia albida*—a N-fixing tree that drops its leaves during the crop season, reducing competition for light—

are 20–40% higher than in open fields, attributable to soil nitrogen improvement, soil moisture conservation, and microclimate moderation.

10. IFS Case studies from India

10.1 Rice-Fish Integration in Eastern India

Rice-fish integration—the simultaneous culture of fish in rice paddies—is one of the oldest and most widespread IFS practices in Asia, with documented history dating back over 2,000 years in China. In India, rice-fish farming is practiced on approximately 1.5 million hectares in the eastern states of West Bengal, Odisha, Assam, Manipur, and Andhra Pradesh, typically on low-lying paddies with natural fish entry or intentional stocking of fingerlings. A 5-year study of rice-fish systems in West Bengal and Odisha by ICAR-CIFA (Central Institute of Freshwater Aquaculture) documented fish yields of 500–800 kg ha⁻¹ season⁻¹ without external feed—pure net income from a component previously unused—representing a 25–40% increase in net farm income over rice monoculture alone.

The ecological benefits of rice-fish systems extend beyond income. Fish consume insect pests (stem borers, leaf folders) and weed seeds, reducing pesticide and herbicide use requirements by 30–50%. Fish excretions contribute 20–30 kg N ha⁻¹ in plant-available form, partially offsetting chemical fertilizer needs. A comparative study across 300 farms in Andhra Pradesh demonstrated that rice yields in rice-fish systems were 8–12% higher than in rice monoculture, attributed to reduced pest pressure, improved soil microbial activity, and organic N contribution from fish.

10.2 Crop-Livestock-Biogas IFS in Maharashtra

The biogas-integrated IFS model—where cattle dung feeds a biogas plant, generating cooking energy and nutrient-rich slurry for crops—is a widely promoted IFS variant in Maharashtra, Gujarat, and Karnataka. A detailed economic analysis of 120 IFS farms in Ahmednagar district, Maharashtra with the model cotton + sorghum + jowar + 3 cross-bred cows + 2 m³ biogas plant demonstrated: annual biogas energy value equivalent to INR 12,000–18,000 (replacing LPG and firewood); annual biogas slurry value equivalent to 60–80 kg chemical N equivalent per hectare (INR 6,000–8,000 in saved fertilizer cost); 30–40% reduction in total farm input expenditure; and net income of INR 160,000–200,000 ha⁻¹ year⁻¹ versus INR 95,000–120,000 for cotton monoculture.

10.3 Coconut-Based IFS in Coastal Andhra Pradesh

Coastal Andhra Pradesh, with its humid climate, alluvial soils, and established coconut cultivation tradition, has developed several high-productivity IFS models based on coconut gardens. The TNAU-developed Coconut + Banana + Vegetables + Layer Poultry + Fish Pond model, adapted for coastal Andhra by ANGRAU (Acharya N.G. Ranga Agricultural University), integrates 200 coconut palms (1 ha), 400 banana plants in alleys between coconut rows, vegetable beds (0.1 ha), 100 layer hens, and a 0.2 ha fish pond in a comprehensive circular IFS. Documented annual income from this model ranges from INR 180,000 to 240,000 ha⁻¹, with coconut, banana, and vegetable income complemented by egg, fish, and poultry manure-based organic fertilizer income streams. This model has been adopted by over 10,000 smallholder farmers in Krishna, West Godavari, and East Godavari districts of Andhra Pradesh.

11. Policy framework and scaling

11.1 Existing Policy Support

Several national and state-level policy instruments support IFS development in India. The National Mission for Sustainable Agriculture (NMSA) under the National Action Plan on Climate Change (NAPCC) provides funding for soil health management, water use efficiency improvement, and diversified farming systems-all central elements of IFS. The Paramparagat Krishi Vikas Yojana (PKVY) promotes organic cluster farming compatible with IFS, providing INR 50,000 ha⁻¹ over 3 years for organic IFS adoption. The Pradhan Mantri Fasal Bima Yojana (PMFBY) crop insurance scheme is being extended to cover livestock and horticultural components of IFS.

The National Food Security Mission (NFSM), Rashtriya Krishi Vikas Yojana (RKVY), and National Horticulture Mission (NHM) collectively provide substantial resources for the individual components of IFS-crop production, livestock development, horticulture, and farm pond construction-but rarely in an integrated package approach. Convergence of these schemes under a coordinated IFS promotion framework-as advocated by ICAR and the National Academy of Agricultural Sciences (NAAS)-would substantially enhance efficiency and impact.

11.2 Extension and Capacity Building

Effective extension and capacity building are critical to translating IFS research findings into farmer practice. The complexity of IFS-requiring knowledge across multiple enterprises simultaneously-poses challenges for conventional single-commodity extension approaches. Farmer Field Schools (FFS) adapted for IFS, where farmer groups learn by doing across multiple IFS components through an entire season, have been evaluated as among the most effective modalities for IFS technology transfer in India and Asia. Evaluation studies of IFS-FFS programs in Odisha and West Bengal found that FFS participants adopted 3.5 more IFS components than non-FFS farmers and had 40% higher IFS income after 3 years.

Digital extension platforms-farm advisory apps, WhatsApp-based farmer groups, and AI-powered chatbots-are increasingly being deployed to scale IFS knowledge dissemination beyond the reach of traditional extension systems. The KisanSabha and Kisan Network platforms in India are providing real-time advisory services on IFS components-livestock feeding, fish pond management, vegetable pest control-to thousands of IFS farmers through smartphone interfaces. The potential for precision IFS management through IoT-enabled soil sensors, remote-monitored pond water quality, and drone-based crop scouting is being piloted by agricultural technology companies in partnership with ICAR institutes.

11.3 Market Development

Market development for diversified IFS products is essential for realizing the full income potential of IFS. Individual smallholder IFS farms produce small quantities of diverse products-a few kilograms of fish, some dozens of eggs, a basket of vegetables, liters of milk-that are often difficult to sell in organized markets without aggregation. Farmer Producer Organizations (FPOs) and cooperatives that aggregate production from multiple IFS households enable access to institutional buyers, organized retail, and export markets, capturing value that individual small farmers cannot.

The 'One District One Product' (ODOP) initiative of the Government of India-identifying and promoting a distinctive agri-food product from each district-offers an opportunity to profile IFS-derived specialty products (organic rice, specialty honey, medicinal herbs, traditional dairy products) from IFS regions, building brand identity and premium market access. Several district-level IFS product brands-Palghar Ragi, Koraput Kalajeera Rice, Palakkad Matta Rice-have successfully established geographic indications (GIs) and premium pricing that provide sustained incentives for IFS adoption.

12. Challenges and constraints

12.1 Knowledge and Skills Complexity

IFS demands a substantially higher level and breadth of agronomic, livestock, and business management knowledge than monoculture farming. Smallholder farmers transitioning to IFS must acquire competence in crop management, livestock health care, fish pond management, composting, and basic marketing and accounting-a formidable knowledge requirement that extension systems are often ill-equipped to address comprehensively. This knowledge gap is a primary constraint on IFS adoption, particularly for older farmers with limited formal education and for farmers in remote areas with limited extension reach.

12.2 Land and Water Resource Constraints

The ICAR IFS models are typically designed for 1-ha farms, but many Indian smallholders operate on even smaller landholdings-average farm size in Andhra Pradesh is approximately 0.75 ha. Below a critical minimum farm size, the economies of scale required for viable livestock and aquaculture integration are difficult to achieve on individual farms, making collective IFS models at the hamlet or village level more appropriate. Water availability for pond construction and supplemental irrigation is also a constraint in water-scarce dryland zones, limiting the applicability of aquaculture-integrated IFS in semi-arid regions.

12.3 Institutional and Infrastructure Gaps

IFS development is hindered by institutional fragmentation-crop, livestock, fisheries, and horticulture are managed by separate government departments with distinct administrative structures, budgets, and extension systems, making coordinated IFS promotion across components administratively challenging. Similarly, physical infrastructure gaps-cold chains for perishable IFS produce, rural road networks for market connectivity, reliable rural electricity for processing-constrain IFS value chain development in many regions. Addressing these institutional and infrastructure gaps requires deliberate policy design and sustained investment beyond what conventional agricultural development programs provide.

13. Future perspectives

13.1 Digital Agriculture and Precision IFS

The integration of digital technologies with IFS management is an emerging frontier with transformative potential. Precision agriculture tools-remote sensing-based crop monitoring, IoT soil and microclimate sensors, smartphone-based disease diagnosis apps-can optimize management of individual IFS components with unprecedented specificity. Machine learning-based IFS decision support systems can optimize component mix and resource allocation decisions for individual farm contexts, integrating real-time weather,

market price, and soil data to generate dynamic management recommendations.

Blockchain-based traceability systems for IFS products-linking farm-level production data with consumer-facing product information-can verify organic, climate-smart, or fair trade credentials, unlocking premium market access and building consumer trust in IFS products. The digitalization of IFS value chains through platform commerce models-connecting IFS farmer collectives directly with urban consumers through farm-to-table digital platforms-has demonstrated significant income uplift for early adopters in Maharashtra, Karnataka, and Kerala.

13.2 IFS and Circular Bioeconomy

The circular economy principles at the heart of IFS-waste elimination, resource cycling, and regenerative production-align perfectly with emerging bioeconomy frameworks that seek to replace fossil-fuel-based inputs with bio-based alternatives. IFS farms generating biogas from livestock waste, producing organic fertilizer from composted manures, and cultivating diverse bioproducts (essential oils, medicinal herbs, specialty foods) are early exemplars of circular bioeconomy agriculture. Scaling this approach through rural bio-enterprise clusters-where multiple IFS farms collectively operate value-added processing units for biogas, compost, and specialty food production-represents a high-potential model for rural economic development.

14. Conclusion

This comprehensive review of integrated farming systems (IFS) in smallholder agriculture presents compelling scientific evidence that IFS represents a transformative paradigm for sustainable livelihoods, food security, and environmental health in smallholder agricultural contexts. The following key conclusions emerge from the synthesis:

IFS delivers consistently higher economic returns-40–75% more annual net income per hectare—than monoculture or conventional farming systems, with substantially lower income variability, confirming IFS as a superior risk-adjusted livelihood strategy for resource-poor smallholders. The resource use efficiency advantages of IFS-30–60% higher land productivity, 20–40% higher water productivity, and 40–60% reduction in external N fertilizer requirements-translate to both economic and environmental gains, demonstrating the compatibility of productivity and sustainability in well-designed IFS.

IFS contributes directly to household food and nutritional security through production of diverse foods on-farm, with documented improvements in dietary diversity scores (45–65%), protein intake (55–65%), and child nutritional indicators (28–35% reduction in stunting rates) compared to non-IFS households in comparable contexts. Soil health and environmental indicators-soil organic carbon, microbial biomass, biodiversity, and GHG emission intensity-are significantly superior in IFS systems compared to monoculture, confirming the ecological sustainability of IFS over the long term.

Climate resilience-a defining requirement of 21st-century agriculture-is intrinsic to the diversified structure of IFS, with empirical evidence demonstrating 35–50% lower income variability under climate stress in IFS versus monoculture households. The agroforestry, organic cycling, and water management dimensions of IFS contribute to both climate adaptation and mitigation.

Scaling IFS to the level required to address India's and the developing world's food, nutrition, and livelihood challenges demands systemic transformation: convergence of agricultural development schemes under integrated IFS promotion frameworks; targeted capital subsidy and credit programs for marginal farmer IFS adoption; IFS-adapted extension modalities including FFS, digital platforms, and peer-to-peer learning networks; market development through FPOs, value chain platforms, and GI branding; and policy mainstreaming of IFS metrics into national food and agricultural planning. Integrated farming systems are not merely an agronomic option-they are a development imperative for sustainable, equitable, and climate-resilient rural transformation.

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