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Integrated crop-livestock farming systems for sustainable agricultural development in India: A review

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Abstract
Integrated Crop-Livestock Farming Systems (ICLFS) are increasingly recognized as a viable pathway for achieving sustainable agricultural development in India, particularly in the context of small and marginal farming. This review synthesizes recent national and international evidence on the role of ICLFS in enhancing productivity, profitability, soil health, climate resilience and circular bioeconomy outcomes. Drawing on ICAR-led on-farm trials, State Agricultural University studies and peer-reviewed literature, the paper highlights that integrated systems outperform specialized cropping in terms of system productivity, net farm income and employment generation by effectively recycling crop residues and livestock waste into high-value outputs. Empirical evidence indicates that well-designed Integrated Farming System (IFS) models can increase net farm income by 2-4 times, generate 250-450 additional man-days of employment per hectare annually, and meet 30-60% of crop nutrient requirements through internal recycling. The review further demonstrates that ICLFS contribute to climate-smart agriculture by reducing yield variability, improving soil organic carbon stocks, enhancing water-use efficiency and lowering greenhouse gas emission intensity per unit of output. At the same time, adoption is constrained by biomass competition, labour demands, fodder and water scarcity, animal health risks and weak market linkages. The paper proposes a conceptual framework and policy-relevant strategies—aligned with ICAR priorities and the National Innovations in Climate Resilient Agriculture (NICRA)—to scale ICLFS through location-specific designs, strengthened extension, manure-to-value innovations and institutional support. Overall, ICLFS emerge as a cornerstone for sustainable intensification, income diversification and resilient agricultural systems in India.

Keywords: Integrated farming system, crop-livestock integration, India, ICAR, nutrient recycling, soil health, climate resilience, circular bioeconomy, sustainable intensification

Introduction
India's agriculture faces the complex challenge of ensuring food and nutritional security for a population exceeding 1.4 billion, while operating under increasing constraints of land fragmentation, soil degradation, water scarcity, market volatility, and climate change. According to the Agricultural Census 2015-16, more than 86% of Indian farmers are small and marginal, cultivating less than 2 ha of land, which limits economies of scale and increases vulnerability to production and income shocks. Simultaneously, nearly 30% of Indian soils are degraded due to nutrient mining, declining soil organic carbon and imbalanced fertilizer use, while agriculture accounts for about 80% of freshwater withdrawals, intensifying pressure on water resources.
Mixed crop-livestock systems have historically underpinned smallholder livelihoods in India, contributing to food production, draft power, nutrient recycling and income stability. Livestock plays a particularly critical role, contributing around 30-31% to agricultural Gross Value Added (GVA) and supporting the livelihoods of more than 70 million rural households. India is the world's largest milk producer, with production exceeding 230 million tonnes annually, underscoring the importance of crop-livestock linkages for feed supply and residue utilization. However, recent intensification trajectories in several regions have favoured enterprise specialization, often leading to increased dependence on external inputs, higher production costs, nutrient imbalances and greater exposure to climate and price risks.

Integrated crop-livestock farming systems (ICLFS) offer a systems-based alternative that emphasizes complementarities between crops and animals. In such systems, crops provide food, fodder and residues, while livestock convert biomass into high-value products such as milk, meat and eggs, and generate manure and urine that can be recycled to agricultural soils. Empirical studies from India indicate that 30-60% of crop nutrient requirements can be partially met through recycled organic sources in well-managed integrated farming systems, leading to improvements in soil organic carbon, nutrient-use efficiency and water-holding capacity. By closing nutrient loops and diversifying production, ICLFS enhance total factor productivity at the farm level while reducing reliance on synthetic fertilizers and purchased feeds.

Recognizing these advantages, the Indian Council of Agricultural Research (ICAR) and State Agricultural Universities (SAUs) have developed and validated several location-specific Integrated Farming System (IFS) models, such as crop-dairy, crop-fish-poultry, crop-horticulture-livestock and diversified models incorporating mushroom cultivation, vermicomposting and biogas units. Results from ICAR on-farm trials demonstrate that IFS models can increase net farm income by 2-4 times, generate 250-400 additional man-days of employment per year, and improve income stability compared to sole cropping systems, particularly for small and marginal farmers.

Recent literature further highlights the climate-smart and circular economy dimensions of crop-livestock integration. Integrated systems enhance resilience by spreading risk across multiple enterprises, improving recovery after climatic shocks, and enabling efficient reuse of farm by-products. From a mitigation perspective, improved feed efficiency, manure management and fertilizer substitution in ICLFS can reduce greenhouse gas emission intensity per unit of output, even though absolute emissions from livestock remain a concern. These attributes align closely with national priorities such as sustainable intensification, National Innovations in Climate Resilient Agriculture (NICRA), and the broader transition toward a circular bioeconomy in Indian agriculture.

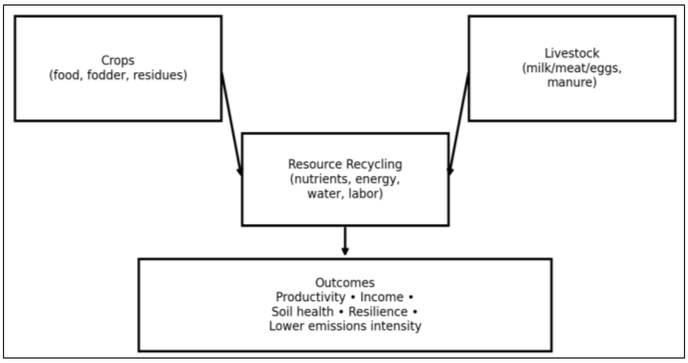
Against this backdrop, the present review synthesizes recent (2020-2024) national and international evidence on integrated crop-livestock farming systems, with a primary focus on Indian agriculture. The review examines system concepts, sustainability outcomes, constraints and enabling conditions, and proposes a conceptual framework and policy-relevant pathways for scaling ICLFS. The structure and emphasis of the paper are aligned with the expectations of NAAS- and ICAR-oriented journals, aiming to inform researchers, extension professionals and policymakers engaged in advancing sustainable and resilient farming systems in India.

Methodology

This is a narrative review with targeted inclusion of recent peer-reviewed literature indexed in Scopus/Web of Science along with selected ICAR e-publishing outputs and authoritative institutional sources. Search terms included combinations of "integrated crop-livestock", "integrated farming system", "nutrient recycling", "soil health", "climate-smart", "India", and "smallholder". Studies were prioritized when they (i) reported quantitative indicators (system productivity, net returns, nutrient budgets, soil properties), (ii) described farm/system designs or models in Indian contexts, or (iii) addressed sustainability metrics (emissions, circularity, resilience). Evidence was synthesized thematically across five domains: (a) system concepts and typologies, (b) biophysical performance, (c) socio-economic performance, (d) environmental and climate outcomes, and (e) adoption/policy.

Conceptual Framework

The conceptual framework (Figure 1) links crop and livestock components through resource recycling and system circularity, producing outcomes for productivity, profitability, soil health, resilience and emissions intensity.



Typologies of ICLFS in Indian Agriculture-Indian ICLFS are diverse, shaped by agro-ecology, irrigation, market access, and household assets. Table 1 summarizes common typologies, indicative benefits and primary constraints.

Typology of Integrated Crop-Livestock Farming Systems (ICLFS) in India

ICLFS Typology (India)	Typical Components	Key Sustainability Benefits	Common Constraints / Trade-offs
Crop-dairy (dominant mixed system)	Cereals/pulses + fodder crops + cattle/buffalo	Manure recycling; steady cash flow; draft and transport services	Feed and fodder deficits; heat stress; methane emissions and manure management
Rice-based integrations	Rice + fish/poultry/duck + vegetables	Nutrient recycling; diversified food basket; improved water productivity	Water quality issues; biosecurity risks; seasonal labour peaks
Dryland crop-small ruminant systems	Millets/pulses + goats/sheep	Risk buffering in drought years; use of common property resources	Overgrazing pressure; disease outbreaks; market volatility
Horticulture-livestock systems	Fruits/vegetables + dairy/goat/poultry + compost/vermicompost	High value per unit land; residue-to-compost nutrient loop; year-round employment	High perishability; cold-chain needs; higher management intensity
Integrated Farming System (IFS) models	Crops + dairy + fish + poultry + mushroom + vermicompost/biogas	Multiple revenue streams; internal resource cycling; higher employment	Higher skill and labour requirements; initial investment; coordination challenges

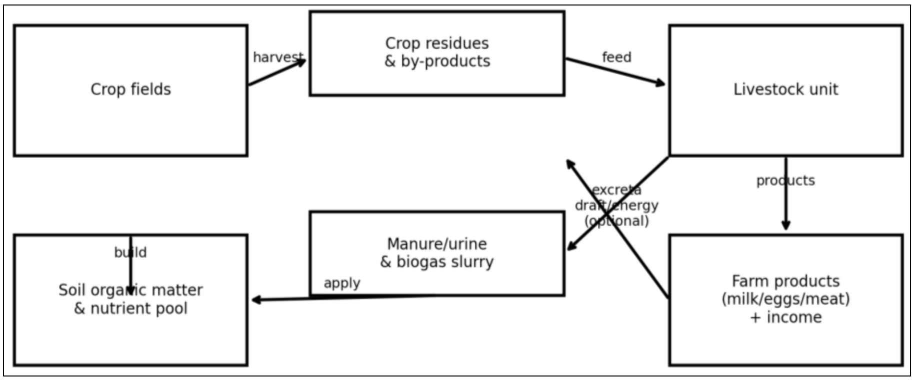


Fig 2: Simplified nutrient and biomass flows in ICLFS (crop residues → livestock; manure/slurry → soil).

Results and Discussion

Productivity and Profitability Outcomes- Evidence from Indian Integrated Farming System (IFS) trials and global mixed-farming studies consistently demonstrates that integrated crop-livestock systems outperform specialized cropping systems in terms of overall system productivity, profitability and employment generation. The superior performance of ICLFS arises from their ability to convert low-value and often underutilized by-products—such as cereal straw, crop residues, bran, weeds and household organic waste—into high-value outputs, including milk, meat, eggs, fish and organic manure. This internal recycling substantially enhances total factor productivity at the farm level and reduces dependence on purchased inputs. Results from ICAR-led multi-location trials indicate that diversified IFS models can increase system productivity by 1.5 to 3.0 times compared to conventional sole cropping. Using sugarcane equivalent yield (SEY) as a common metric, several IFS models have reported productivity levels ranging from 25-45 t ha^{-1} yr^{-1}, compared to 8-12 t ha^{-1} yr^{-1} under traditional cereal-based systems. In a comprehensive IFS model evaluated for small farm holders in Uttar Pradesh, integration of crops with horticulture, fishery, mushroom cultivation, poultry and vermicomposting resulted in a SEY exceeding 30 t ha^{-1}, alongside marked improvements in yield stability across seasons (Meena *et al*., 2022).In economic terms, integrated systems show substantial gains in net returns and benefit-cost ratios. ICAR studies report that annual net farm income from IFS models typically ranges between ₹1.5-3.5 lakh ha^{-1}, compared to ₹0.6-1.0 lakh ha^{-1} from sole cropping under similar agro-ecological conditions. Benefit-cost ratios in diversified IFS often exceed 2.0-2.5, reflecting lower variable costs due to on-farm feed and nutrient recycling. Importantly, livestock components—particularly dairy and poultry—contribute 40-60% of total farm income, providing regular cash flow and buffering farmers against crop failure and price volatility. Integrated systems also perform better in terms of employment generation, a critical indicator for smallholder sustainability. Studies across different states show that IFS models generate 250-450 man-days of employment per hectare per year, compared to 120-180 man-days under conventional cropping systems. Enterprises such as dairy, mushroom cultivation, poultry and vermicomposting ensure year-round labour utilization, thereby reducing seasonal unemployment and distress migration in rural areas. From a risk perspective, income diversification in ICLFS significantly improves income stability. Empirical evidence suggests that diversified farms experience 20-35% lower income variability compared to specialized systems, particularly in years affected by droughts, floods or market shocks. Livestock and allied enterprises act as risk buffers, providing assured returns even when crop yields are adversely affected. Overall, the productivity and profitability evidence strongly supports integrated crop-livestock farming systems as a viable pathway for sustainable intensification in Indian agriculture. By enhancing system productivity, increasing farm income, generating employment and stabilizing returns, ICLFS align closely with national priorities of doubling farmers' income, inclusive growth and resilient agricultural development.

Residue recycling, nutrient budgeting and soil health

A defining advantage of ICLFS is internal nutrient supply through recycling. In a rice-based integrated farming study, approximately 10 tonnes of organic matter were recycled annually, with the dairy unit contributing about half, and the internal nutrient supply from recycling was estimated at 55 kg N, 17 kg P and 76 kg K—equivalent to sizeable quantities of mineral fertilizers—contributing to reduced input costs and improved soil health.

Table 2: Summarizes key sustainability pathways and measurable indicators that are widely used to evaluate ICLFS performance.

Sustainability pathway	Mechanism in ICLFS	Indicative indicators (examples)
Nutrient recycling	Manure/urine/biogas slurry returned to fields; reduced fertilizer dependency	N, P, K budgets; fertilizer substitution rate; nutrient-use efficiency
Soil health	Increased organic inputs and ground cover; improved aggregation	Soil organic carbon; bulk density; microbial biomass; infiltration
Water productivity	Diversified enterprises; better water capture/storage; fodder planning	Water-use efficiency; irrigation intensity; water footprint
Energy & circularity	On-farm reuse of by-products; biogas from dung	Energy output/input ratio; on-farm circularity index; fossil fuel savings
Biodiversity & ecosystem services	Enterprise diversification; habitat niches; reduced chemical intensity	Species richness; pollinator abundance; pesticide use intensity
Resilience	Multiple income streams; staggered harvests; risk spreading	Income variability; shock recovery time; diversification indices
Emissions intensity	Better feed efficiency; manure management; fertilizer substitution	kg CO2e per kg product; methane intensity; N2O from soils (LCA)

Climate resilience and climate-smart integration

Recent empirical evidence increasingly recognizes integrated crop-livestock farming systems (ICLFS) as a climate-smart agricultural (CSA) strategy, particularly in regions exposed to high climate variability. In India, agriculture is highly vulnerable to climate risks, with more than 60% of cropped area rainfed and nearly 70% of droughts and extreme rainfall events directly affecting smallholder-dominated regions. Crop-livestock integration enhances resilience primarily through enterprise diversification, improved soil organic carbon (SOC), efficient nutrient cycling and adaptive capacity. Studies indicate that diversified ICLFS can reduce yield variability by 15-30% compared to monocropping systems under climate stress conditions. Improved soil organic matter through manure and residue recycling increases soil water-holding capacity by 10-20%, thereby buffering crops against dry spells. For humid tropical smallholders, climate-smart crop-livestock integration has been shown to increase system productivity by 20-40%, improve household food security indices, and enhance carbon sequestration potential by 0.2-0.5 t C ha^{-1} yr^{-1} (Swarnam *et al*., 2024).From a mitigation perspective, integrated systems contribute to lower greenhouse gas (GHG) emission intensity (emissions per unit output) through improved feed efficiency, optimized herd size, and partial substitution of mineral fertilizers with organic sources. Studies from mixed farming systems in South Asia suggest that 20-35% of synthetic nitrogen fertilizer use can be offset by manure recycling, thereby reducing indirect N_2O emissions from soils. Bibliometric analyses further confirm a growing research focus on soil carbon sequestration, nitrogen storage and system optimization in crop-livestock systems, reflecting their increasing relevance in climate adaptation and mitigation research (Yang *et al*., 2022).These benefits closely align with national initiatives such as National Innovations in Climate Resilient Agriculture (NICRA) and India's commitments under the Nationally Determined Contributions (NDCs), where integrated farming systems are recognized as a pathway to climate-resilient and low-emission agriculture.

Circular Bioeconomy and Waste-to-Value Innovations

Integrated crop-livestock farming systems are inherently aligned with circular bioeconomy principles, as they emphasize recycling of on-farm biomass and minimization of waste. In conventional systems, large quantities of crop residues and animal wastes remain underutilized or are improperly managed, leading to nutrient losses and environmental pollution. India produces an estimated 500-550 million tonnes of crop residues annually, of which a significant portion is either burned or inefficiently used, contributing to air pollution and carbon emissions. In ICLFS, crop residues are strategically used as livestock feed, bedding or composting material, while livestock manure and urine are recycled as soil amendments. Recent integrative reviews position crop-livestock systems as a central pillar of circular agriculture by enabling closed nutrient loops and waste-to-value pathways. Empirical studies indicate that 60-80% of farm-generated organic waste can be recycled within well-managed IFS models, significantly reducing the need for external inputs. the Indian context, biogas, vermicomposting and composting represent scalable waste-to-value innovations. A single dairy animal can produce 10-15 kg dung day^{-1}, which, when used in biogas plants, can generate 1.5-2.0 m^3 biogas day^{-1}, sufficient to meet household cooking energy needs while producing nutrient-rich slurry. Biogas slurry and vermicompost have been shown to improve soil organic carbon and supply 25-40% of crop nitrogen requirements, simultaneously enhancing soil structure and microbial activity. These circular approaches contribute to clean energy generation, nutrient efficiency and income diversification, reinforcing the sustainability of integrated systems.

Adoption Constraints, Trade-Offs and Enabling Conditions-

Despite their demonstrated advantages, the large-scale adoption of ICLFS in India remains constrained by several biophysical, socio-economic and institutional factors. One of the most critical trade-offs is biomass competition, where crop residues are required both for soil cover (mulching and conservation agriculture) and as livestock feed. Studies suggest that in cereal-based systems, 50-70% of residues are diverted to livestock feeding, potentially limiting residue retention for soil health unless fodder alternatives are developed. Integrated systems are also labour- and management-intensive, requiring 20-40% more labour inputs than sole cropping systems. These labour demands often have a gendered dimension, with women disproportionately involved in livestock care, manure management and allied enterprises, highlighting the need for gender-sensitive technologies and institutional support. Additionally, animal health and biosecurity risks, including periodic disease outbreaks, can significantly affect productivity and farmer confidence. Other major constraints include fodder and water scarcity, limited access to credit and insurance, and weak or fragmented value chains for milk, meat, eggs and organic manure products. In many regions, lack of cold-chain infrastructure and organized markets reduces price realization, particularly for smallholders. Institutional assessments indicate that inadequate extension coverage and limited convergence between crop and livestock departments further slow adoption. Enabling conditions for scaling ICLFS include location-specific ICAR/SAU IFS models, fodder intensification strategies (multi-cut fodders, silage, fodder legumes), improved manure management technologies, and strong farmer producer organizations (FPOs) and cooperatives. Empirical evidence shows that farmers linked to dairy cooperatives and FPOs realize 15-25% higher prices and experience reduced market risk. Figure 3 synthesizes the major constraints and enabling interventions relevant to Indian smallholder agriculture.

Policy and Research Recommendations

The following priorities can accelerate sustainable scaling of ICLFS in India:

Strengthen ICAR-SAU-KVK extension packages for location-specific ICLFS modules and enterprise combinations.

Invest in fodder and feed systems (seed systems for fodder crops, community silage pits, pasture restoration, Azolla where suitable).

Promote manure-to-value chains (compost standards, biogas/CBG linkages, nutrient management advisory) to reduce nutrient losses and emissions.

Improve animal health infrastructure: preventive vaccination, disease surveillance, and biosecurity training.

Enable credit and risk management products tailored to mixed farms (bundled crop + livestock insurance; working capital for feed).

Support market integration via cooperatives/FPOs and decentralized processing (milk chilling, mini-dairies, poultry/fish value addition).

Encourage rigorous assessments: life-cycle assessment (LCA) for emissions intensity, ecosystem services valuation, and gendered labor analysis.

Conclusion

Integrated Crop-Livestock Farming Systems represent a robust and context-appropriate strategy for advancing sustainable agricultural development in India. The evidence reviewed in this paper clearly demonstrates that ICLFS enhance system productivity, farm profitability, employment generation and income stability by promoting efficient recycling of biomass and nutrients and by diversifying farm enterprises. ICAR and SAU experiences show that integrated farming system models are particularly effective for small and marginal farmers, enabling substantial gains in net income and resilience while reducing dependence on external inputs. Beyond economic benefits, ICLFS contribute significantly to environmental sustainability by improving soil organic carbon, nutrient-use efficiency and water-holding capacity, while supporting climate-smart agriculture objectives through reduced yield variability and lower greenhouse gas emission intensity per unit of output. Their strong alignment with circular bioeconomy principles—through waste-to-value pathways such as composting, vermicomposting and biogas—further enhances their relevance under current sustainability and clean energy transitions. However, widespread adoption of ICLFS is constrained by trade-offs related to biomass competition, labour intensity, fodder and water scarcity, animal health risks and weak value chains. Addressing these challenges requires coordinated policy and institutional support, including location-specific ICAR/SAU models, fodder intensification, improved animal health services, access to credit and insurance, and stronger farmer producer organizations and cooperatives. In conclusion, integrated crop-livestock farming systems offer a practical and scalable pathway for sustainable intensification, livelihood security and climate resilience in Indian agriculture. Future research should focus on long-term, multi-location evaluations, life-cycle assessment of emissions intensity, ecosystem service valuation and gender-responsive system design to further strengthen the scientific and policy foundations for scaling ICLFS nationwide.

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