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ORIGINAL ARTICLE

Integrated farming system approaches to achieve food and nutritional security for enhancing profitability, employment, and climate resilience in India

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Abstract

Integrated farming systems (IFS) entail a holistic approach to farming aimed at meeting the multiple demands (impart farm resilience, farmer livelihoods, food security, ecosystem services, and making farms adaptive and resilient, etc.). IFS are characterized by temporal and spatial mixing of crops, livestock, fishery, and allied activities in a single farm. It is hypothesized that these complex farms are more productive at a system level, are less vulnerable to volatility, and produce less negative externalities than simplified farms. Thereby, they cater the needs of small and marginal farmers, who are the backbone of agriculture in India. Our review of literature shows that IFS have the potential to improve farm profitability (265%) and employment (143%) compared to single enterprise farms. The literature showed that IFS enhance nutrient recycling through composting, mulching, and residue incorporation and, as a consequence, have the capacity to reduce the external purchase of inputs. The nutrient recycling in turn helps to increase the soil quality indicators such as soil nutrient availability and also improves soil microbial activity. The IFS play a major role in biodiversity conservation through adoption of diversified cropping system and through integration of indigenous livestock breeds. IFS also played important role in improving soil organic carbon from 0.75 to 0.82%. Due to increased carbon sequestration, biomass production by trees, reduced consumption of fertilizers, and pesticides the greenhouse gas emission could be reduced significantly. This results in a linked system making it sustainable and climate-resilient. The main challenge associated with adoption of IFS is it requires skill, knowledge, resources, labor, and capital which are not always available with small and marginal farmers. There is a need for integrating productivity, profitability, and environmental sustainability variables in a single evaluation framework to effectively generate information toward enhancing adaptability of IFS.

KEYWORDS
agroecosystem, climate resilience, cropping system, farming system, sustainability

1 | INTRODUCTION

Agriculture is the backbone of the Indian economy; nearly 60% of the Indian population directly depends on agricultural activities as a source of livelihood. Indian agriculture is dominated by small and marginal farmers (86%), having only 44% of the total arable land (GOI, 2014). In 2010–2011, the average size of an operating land holding was 1.16 ha, and farm size has been further reduced due to fragmentation. In Indian states like Bihar and Kerala, the average size of a holding has been reduced by more than 60%, and in Andhra Pradesh, Karnataka, Madhya Pradesh, and Maharashtra, farm size has been halved (Roy, 2014). The fragmentation of land resources is posing a serious threat to future sustainability, food security, and profitability of Indian farming (Siddeswaran et al., 2012). The Indian marginal and small farmers are mostly concentrating on cereal-based crop production with high risks of climate anomalies such as floods and droughts. Due to these aberrations, farmers are unable to get sufficient income to sustain their family (Kumar et al., 2006, 2018). Marketized farming is mostly practiced as a result of higher labor costs, resulting in lower to minimal profitability. The rising cost of food and energy, depleting water supply, diminishing farm size, soil degradation, imbalanced fertilizer use, excessive use of agrochemicals, and climate change are all contributing to the problems of agricultural production system (Paroda, 2012). These problems are posing a serious threat to production and socioeconomic and environmental sustainability of agriculture. Hence, the increasing area under agriculture to meet the burgeoning food demand is under threat.

The modern agricultural production systems are simplified due to specialization and are intensified with high rates of external inputs to keep production conditions favorable and constant. These systems can be efficient and productive, but they habitually end up with causing environmental problems, depletion of soil nutrients, affecting soil biota, and leading to higher cost of production (Devendra & Thomas, 2002). Likewise, intensive livestock enterprises such as large dairy, poultry industry, piggery industries, and animal feed preparations are dependent on external inputs (e.g. feed), thereby both externalizing pollution (for the production of inputs) and generating pollution hazards locally due to poor handling, storage, and disposal (Parajuli et al., 2018). These modern, specialized, and intensive agricultural practices affect the diversity in flora and fauna and increase vulnerability of resource poor farmers to weather and market fluctuations due to dependency on less agricultural commodities (Manjunath et al., 2018; Paramesh, Arunachalam, et al., 2019; Paramesh, Parajuli, et al., 2019). Intensive agriculture systems in India are unable to provide regular income and employment, failing to achieve food, environmental, and energy security at the farm level. So, farmers depending on single farm enterprise, such as a typical monocropping system, are unable to sustain their livelihood.

To overcome the problems encountered by specialized, input driven agriculture, the integration of crops, livestock, fishery components that sustains food, and nutritional security with regular and periodic income to farmers is vital (Gill et al., 2009). Integrated farming systems (IFS) that integrate animal and crop enterprises are receiving renewed interest in marginal, small, and medium farmers (Behera et al., 2013; Behera & France, 2016), who cultivate less than one hectare. The IFS approach encourages ecological intensification and aims to reduce use of anthropogenic inputs with enhanced ecosystem functioning (Bell & Moore, 2012) like nutrient recycling, soil formation, soil fertility enhancement, and improving environmental performance (Salton et al., 2014). Efficiently managed IFS are expected to be less risky, as they benefit from enterprise synergies, product diversity, and ecological reliability (Behera & France, 2016).

The two main features of an IFS are residue recycling (wastes or by-products of one component become an input to another component) and improved land-use efficiency (two subsystems occupy part or all of the space required for each sub-system). The components/enterprises in the IFS differ from region to region, depending on agro-climatic situations *viz.*, the land type, water availability, socioeconomic condition of the farmers, and market demand (Devendra & Thomas, 2002; Singh et al., 2008). There is a need to establish effective linkage and complementarities between components to develop effective holistic farming systems (Bell & Moore, 2012). For the development of the farming community, IFS in terms of mixed farming systems has got the attention of the Indian government, and several programs were formulated, to bring livelihood security of small and marginal farmers and to usher agriculture, and livestock production (Behera et al., 2013; Mahapatra & Behera, 2011).

Despite the complexity of how potential food and nutritional demand will grow, the region specific IFS in India will be crucial in helping to satisfy this demand. A further difficulty is that the production strategy to satisfy food demand would take place in the face of climate change and uncertainty. Considering the importance of IFS in food and nutritional security, economics, biodiversity conservation, climate resilience, residue recycling, and employment generation to the farm family, an attempt has been made to collect the published research outputs and perform a detailed review of the same. The objective of the study was to review the significance of IFS in India to achieve food security, increasing nutrient recycling, and for climate resilience. We also discussed the importance of IFS and what is learned about the possible impacts of climate change on IFS in developed countries.

2 | REVIEW OF LITERATURE

We systematically searched for scientific literature using the following search terms in Google Scholar: "Farming system AND Production AND Income or Economics AND Employment generation or Food and Nutritional Security," of which the first 102 results were selected. Studies were selected if they included a comparison between cropping system and IFS system with equivalent yield and net returns. We collected further records from the reference lists of review articles and research articles meeting the initial eligibility criteria. Targeted searches of governmental and independent agricultural research organizations were also performed where medium-to-large scale, commercially oriented IFS are known to occur.

- The study scope was extended to agri-pastoral systems with annual crops and perennial crops. Duck-rice-azolla, agro-silvopastoral systems, and cropping systems integrating livestock were considered.
- The study involving different landholding size was also considered.
- Crops and livestock spatially integrated in the same field were considered.
- Both on-farm (farmers field-farmers own IFS practice) and on-station (research station trails conducted with combination of enterprises) trials were considered.
- The study covering original research, dataset, or dissertation, that is not a review, book chapter, or conference proceeding was also considered.

Irrespective of the farm holding size, the literatures were selected and data were obtained. Single study consisting comparison of cropping and multiple IFS systems was also selected, and a mean value was obtained for IFS systems and comparison was made. Data were extracted from articles, integrated into one database with the same units of measurement: One ha was used as the unit for surface area and 1 year as the unit for time. As in all the studies comparison was made between the single enterprise (mostly cropping system) and IFS and there was no design was followed for statistical analysis. A total of 78 articles are included in this review, which were published between 1990 and 2020 as these cases provided data involving IFS, in comparison with a single enterprise. The articles contained data from rainfed, irrigated, coastal, hill, mountain, and arid agro-ecosystem of the country. The percent improvement in equivalent yield, net income, and employment over single enterprise was calculated for comparison.

$$\text{Percent improvement} = \frac{\text{Income in IFS} - \text{income in Single enterprise}}{\text{Income in single enterprise}} \times 100$$

3 | LITERATURE FINDINGS

3.1 | Effect of integrated farming system on farm income

The literature revealed scope of IFS in improving farm profitability through increasing net income by 265% over the single enterprise. About 14% increase in net income was recorded in Rice-rice-Azolla/Calotropis + Fish (Shanmugasundaram et al., 1995) to 1838% in Crops + pigeon + buffalo + agroforestry + farm pond (Shekinah & Sankaran, 2007) over monocrop/single enterprise (Table 1 & Figure 1). The IFS systems involving different land-based enterprises generated net returns of USD 5050 than conventional rice–wheat system (USD 1258; Bhargavi & Behera, 2020). The higher net income in IFS was due to decreased production costs by recycling by-products and residues of different components within the system. The input cost especially critical inputs like fertilizers, pesticides, and herbicides consumption can be reduced by the adoption of IFS through encouraging resource flow and integrated pest and nutrient management. The higher product diversification in IFS especially from livestock (dairy and poultry) has the potential to generate daily income for small and marginal farmers. The inclusion of high-value vegetables and spice crops in the farm is much more remunerative rather than long-duration mono-cropping. The livestock component such as dairy, goatery, poultry, and piggery will act as farm insurance at the time of crop failure. Jayanthi et al. (2003) showed 25% higher economic returns due to crop integration with fish and poultry under lowland conditions of Tamil Nadu. Rautaray et al. (2005) reported that the rice-–fish system under lowland ecologies of Assam with vegetables, fruits, ornamental plants, and agroforestry components on dyke area has potential to produce 2.8 times higher income over rice alone. The coconut-based IFS at ICAR-CPCRI, Kasaragod, produced 19125 nuts, 9275-liter milk, 526 kg poultry, 50 kg Japanese quail bird, and 400 kg fish from 1.04 ha. Further, this IFS system revealed a gross and net return of USD 2762 and USD 889 per annum, respectively (Reddy & Biddappa, 2000). So, IFS could be promoted as major livelihood option for small and marginal farmers of the

TABLE 1 Net income (USD) of cropping system and integrated farming system (IFS)

Sl no.	Single enterprise	Net income	Integrated farming system	Net income	% Improvement	References
1	Maize + pigeonpea, Cotton + pigeonpea	486	Rice, Cotton, Pigeonpea, Buffalo, Cow, Bullock	947	95	Rao et al. (2017)
2	Cotton, Maize + pigeonpea, Pigeonpea	1129	Cotton, Chrysanthemum, Fodder, Sorghum, Rice, Pigeonpea, Turmeric, Tomato + Bullock + Cow + Buffalo,	2443	116	Rao et al. (2017)
3	Rice-Rice	288	Rice-fish-poultry	648	125	Channabasavanna and Biradar, (2007)
4	Rice-rice-blackgram	111	Rice-rice-cotton + maize + poultry/fish	229	107	Shanmugasundaram et al. (1995)
5	Rice-rice	204	Rice-rice-Azolla/Calotropis + Fish	233	14	Balusamy et al. (2003)
6	Rice-rice-rice-fallow pulses	184	Rice-rice-rice-fallow-cotton + maize + duck cum fish	322	75	Ganeshan et al. (1990)
7	Cropping alone	483	Cropping + fish + goat	1748	262	Jayanthi et al. (2003)
8	Rice	306	Rice + Azolla + fish	424	38	Balusamy et al. (2003)
9	Cashew	484	Rice-brinjal + Rice-cowpea + mushroom + poultyr	1005	107	Manjunath and Itnal (2003)
10	Arable farming	321	Crops + Dairy (2cows) + 15 goats + 10 poultry + 10 duck + fish	599	86	Tiwari et al. (1999)
11	Rice-wheat	1083	Rice-wheat + dairy + Fish + piggery	1509	39	Gill et al. (2005)
12	Rice-wheat	575	Rice-wheat + fish + duck + goat	2204	284	Kumar et al. (2012)
13	Rice–maize	780	Rice-maize + fish + duck + goat	2211	184	Kumar et al. (2012)
14	Rice–wheat–moong	1051	Rice-wheat-moong + fish + duck + goat	2170	107	Kumar et al. (2012)
15	Crops alone	885	Crops + dairy + vermicomposting	1860	110	Singh, Burark, et al. (2017), Singh, Burark, et al. (2017)
16	Rice-wheat	886	Rice-wheat + dairy + fishery + piggery	1154	30	Gill et al. (2009)
17	Rice-wheat	844	Rice-wheat + dairy + fishery	1070	27	Gill et al. (2009)
18	Agro-pastoral system	194	Agro-pastoral system + livestock	540	178	Gill et al. (2009)
19	Agri-horti-silvo-pastoral system	349	Agri-horti-silvo-pastoral system + livestock	588	68	Gill et al. (2009)
20	Rice cropping alone	256	Rice – groundnut + mushroom + poultry	809	216	Korikanthimath and Manjunath (2009)

TABLE 1 (Continued)

Sl no.	Single enterprise	Net income	Integrated farming system	Net income	% Improvement	References
21	Rice cropping alone	256	Rice – cowpea + mushroom + poultry	979	282	Korikanthimath and Manjunath (2009)
22	Rice cropping alone	256	Rice - brinjal + mushroom + poultry	1031	302	Korikanthimath and Manjunath (2009)
23	Rice cropping alone	256	Rice – sunnhemp + mushroom + poultry	703	175	Korikanthimath and Manjunath (2009)
24	Rice-wheat	619	Field Crops + goat + Poultry + mushroom	2088	237	Kumar et al. (2012)
25	Rice-wheat	290	Fish + Fodder + livestock + Goat + Duck + Horticulture	1094	277	Kumar et al. (2012)
26	Rice + fallow	353	Fish + horticulture + Vgetables	752	113	Kumar et al. (2012)
27	Makhana	275	Makhana + Fish + Water chestnut	699	154	Kumar et al. (2012)
28	Rice-wheat	296	Cropping + poultry + goatry + mushroom	1192	302	Kumar et al. (2018)
29	Rice-Fallow	209	Crops + dairy + fishery + Recycling	834	298	Das et al. (2018)
30	Rice-vegetables	327	Crops + dairy + fishery + Recycling	834	155	Das et al. (2018)
31	Rice-wheat	1427	Rice-wheat + dairy + kitchen garden + Mushroom	5071	255	Walia et al. (2016)
32	Cropping alone	156	Crops + pigeon + buffalo + agroforestry + farm pond	3023	1838	Shekinah and Sankaran (2007)
33	Rice	1223	Rice + Tuber crops + Fish + Poultry + Goat	3040	149	Nedunchezhiyan et al. (2016)
34	Cotton alone	995	Cotton + Chilli + Pillipesara + Goat + Rabbit + Fodder	2521	153	Vinodkumar et al. (2017)
35	Conventional system (Rice-Maize)	1845	Integrated Farming System	8122	340	Goverdhan et al. (2020)
36	Rice- Wheat system	615	Rice-Wheat + Vegetable + Dairy + Fishery	2012	227	Meena et al. (2013)
37	Rice-Greengram	139	Crop + Vegetables + mushroom + Poultry + Vermi-compost	1041	651	Nath and Barik (2013)
38	Crop alone	1400	Paddy-Groundnut + Maize + Vegetable + Fruit + Piggery + Poultry + Fishery	4847	246	Patra and Samal (2018)
39	Rice alone	170	Rice + dairy + fish	1839	983	Behera et al. (2015)
40	Rice-rice	227	Rice + fish + vegetables	2653	1067	Panda (2016)
41	Crop + Vegetable	500	Crop + Dairy + Goat	1069	114	Singh, Burark, et al. (2017)
42	Arable farming	204	Agri-horti	975	378	Singh, Burark, et al. (2017),

(Continues)

TABLE 1 (Continued)

Sl no.	Single enterprise	Net income	Integrated farming system	Net income	% Improvement	References
43	Arable farming	204	Horti-pasture	569	179	Singh, Burark, et al. (2017),
44	Rice-Fallow	764	Rice-fish	979	28	Dey et al. (2019)
45	Rice alone	280	Rice-fish	994	255	Mohanty et al. (2008)
46	Cotton + Pigeonpea	233	Cotton + Pigeonpea + Bullocks + cow + Goats	1114	378	Gopinath et al. (2013)
47	Horticulture system	769	Horticulture + Fish Culture	1659	116	Laxmi et al. (2015)
48	Tuber crops	758	Tuber crops + vegetables + field crops + livestock	5383	610	Shankar et al. (2018)
49	Tuber crops	970	Tuber crops + vegetables + field crops + livestock + aquaculture	5306	447	Shankar et al. (2018)
Mean	Single enterprise	549	IFS	1737	265	

country to achieve economic and sustained production to meet diverse requirements of the farm household in small and marginal landholding. So, IFS can be considered as a potential approach for rural bio-entrepreneurship and also as an important tool to double the farmer's income in India (Behera & France, 2016).

3.2 | Effect of integrated farming system on employment generation

The Table 2 illustrates the importance of crop and livestock integration to improve the employment opportunity for the farmers and rural youth. The improvement in employment potential under IFS varied from 30% (Shankar et al., 2018) to 485% (Behera & Mahapatra, 1999) (Table 2 and Figure 1) with a mean increase of 143% over single enterprise. Employment generation vary depending on the combination of enterprises chosen. The specialized agriculture practices and mono-cropping increased production cost, risk of crop failure, and lower market price (Manjunath et al., 2017). Due to this, the small and marginal farmers migrated to neighboring cities in search of jobs and livelihood (Paramesh, Arunachalam, et al., 2019; Paramesh, Parajuli, et al., 2019). In this scenario, IFS will be a solution to reduce the economic risk with improved employment generation. The continuous labor requirement for multiple crops and livestock system provides an option for higher employment generation and keeps the farm families engaged in the farm activities. This holds good even during the COVID-19 pandemic for meeting the employment needs of reverse migrants (urban to rural). In IFS, farm activities are continued round the year, thus the farm family effectively engaged in farm. Das et al. (2013) reported significant improvement in employment generation, income, and livelihood of the farmers in crop–fish–pig (pig-based IFS) and crop–fish–duck system over crop alone. Similarly, Surve et al. (2014) showed adoption of IFS as promising and remunerative alternative to an existing soybean–wheat cropping system with higher returns, water productivity, employment generation, and energy output. The Table 3 depicts the employment opportunities offered by the IFS system. The farm family can be effectively engaged in daily care of animals, fodder block, agro-ecotourism activities, production of organic inputs and their marketing, etc.

3.3 | Effect of integrated farming system on residue recycling and soil health

Crop–animal systems in Asian agriculture display a wide diversity in cropping patterns, livestock species, and use

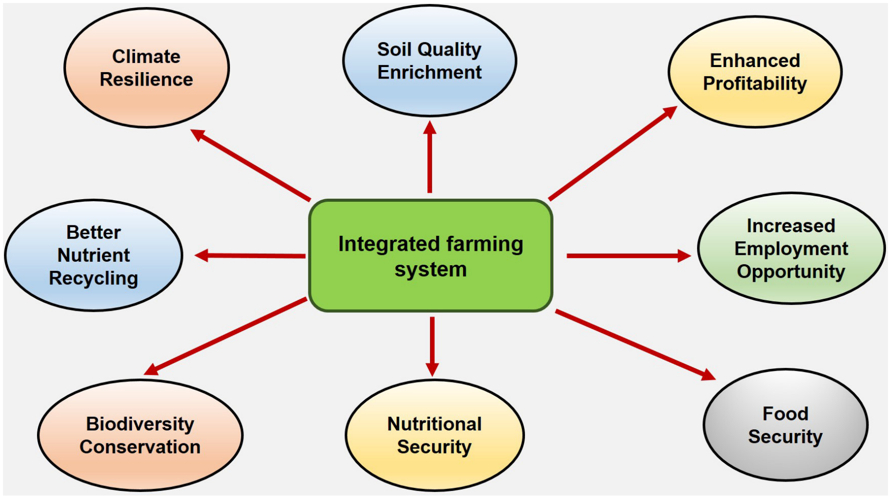

FIGURE 1 Ecosystem services provided by integrated farming system

of the resource base. There is evidence of positive and economic benefits from crop–animal interactions that promote sustainable agriculture and environmental protection (Devendra, 2002; Herridge et al., 2019). Under the stress of intensive agriculture, environmental degradation has been reported in many economically developed countries due to excessive use of high energy inputs such as fertilizers and pesticides. The use and recycling of locally available inputs and integrating them with the minimum needed quantities of external inputs would enhance the sustainability of the farming process. The IFS is the best resource management strategy to reduce dependency on market for inputs and to improve soil health (Hens & Begossi, 2008; Hu et al., 2016; Paramesh, Arunachalam, et al., 2019; Paramesh, Parajuli, et al., 2019). Shekinah et al. (2005) and Sujatha and Bhat (2015) reported enhancement of nutrient use efficiency, nutrient recycling, and higher soil microbial activity when livestock and fisheries, etc. were integrated with crops. The Table 4 depicted potential of nutrient recycling from different IFS models evaluated across the country and highlighted saving in external purchase of nutrients due to efficient recycling in the IFS. All these studies highlighted the advantage of crop–animal integration, boundary plantation, and integrated nutrient management/organic farming practices in enhancing recycling of by-products within the system and reducing dependence on fertilizers. Likewise, agroforestry system/green leaf manuring in IFS has the potential to upgrade the quality of soil, conserves water, and improves carbon stock (Paramesh, Arunachalam, et al., 2019; Paramesh, Parajuli, et al., 2019). Maughan et al. (2009) compared IFS with continuous corn incorporation for soil C and N, and they observed higher total carbon, total nitrogen, water stable aggregates, and microbial biomass carbon in IFS. Further, they reported that IFS improves soil quality, SOC dynamics, and crop yield despite moderate soil compaction caused from cattle presence. Another study at south western Montana including wheat–sheep interaction reported the beneficial effect of sheep grazing during fallow in wheat–fallow systems in enhancing soil C and N levels by returning part of consumed crop residue to the soil through feces and urine (Sainju et al., 2010). The integration of crops and livestock not only provides nutrient rich crop residues and animal manure but also reduces dependency on external purchase. Thus, IFS is an approach that produces residues and manure essential for crop growth and to maintain soil health and also helps in adoption of organic farming system.

3.4 | Effect of integrated farming system on climate resilience

The IFS systems of small and marginal farmers are relatively less depending on purchased inputs due to higher recycling potential of IFS (Table 4 and Figure 1). This implies smallholder mixed farms can be less vulnerable to climate change and crop failure due to higher diversity of farm by-products. The IFS systems from Palampur, Johrat, Kalyani, Raipur, and Telangana reported net negative emission of GHG emission due to higher carbon sequestration (Table 5 and Figure 1). All these IFS system includes boundary plantation with perennial trees or horticulture component (perennial fruit crops). Further, these systems highlighted the increased residue recycling and tree components offset the negative effect of climate change by sequestrating more carbon into the soil and above-ground biomass of the trees. Likewise, Salton et al. (2014) observed net GHG emissions as positive in conventional system and negative in IFS, and this trend was mainly due to higher soil carbon sequestration in IFS system that counterbalanced N_2O emissions. There are numerous ways to improve the complete efficiency and resilience of crop and livestock production systems in the face of climate change. The IFS approach has capacity to reduce CH_4 absorption as observed previously by Dong

TABLE 2 Employment (person days) of integrated farming system (IFS) and cropping system

Sl no.	Single enterprise	Employment	Integrated farming system	Employment	% Improvement	References
1	Cotton, Maize + pigeonpea, Pigeonpea	649	Cotton, Chrysanthemum, Fodder, Sorghum, Rice, Pigeonpea, Turmeric, Tomato + Bullock + Cow + Buffalo,	808	24	Rao et al. (2017)
2	Rice-Rice	437	Rice-fish-poultry	618	41	Channabasavanna and Biradar, (2007)
3	Crop alone	512	Crop + fish + duck + goat	752	47	Kumar et al. (2012)
4	Field crops	98	IFS	573	485	Behera and Mahapatra (1999)
5	Coconut alone	77	Coconut + grass + dairy	356	362	Manjunath and Singh (2005)
6	Cropping alone	369	Cropping + fish + goat	576	56	Jayanthi et al. (2003)
7	Agriculture alone	162	Agriculture + poultry	528	226	Radha et al. (2000)
8	Rice Cropping alone	110	Rice - brinjal + mushroom + poultry	392	256	Korikanthimath and Manjunath, (2009)
9	Rice-wheat	115	Rice-wheat + Vegetable + goat + Poultry + mushroom	287	150	Kumar et al. (2012)
10	Rice-wheat	217	Field crop + Dairy (2) + fish + Duck	492	127	Kumar et al. (2012)
11	Rice-wheat	217	Field Crops + goat + Poultry + mushroom	502	131	Kumar et al. (2012)
12	Rice + fallow	87	Fish + horticulture + Vgetables	148	70	Kumar et al. (2012)
13	Makhana	247	Makhana + Fish + Water chestnut	347	40	Kumar et al. (2012)
14	Rice-wheat	293	Crops + dairy + KG + Mushroom	775	165	Walia et al. (2016)
15	Cropping alone	32	Crop + pigeon + goat + buffalo + agroforestry + farm pond	166	419	Shekinah and Sankaran (2007)
16	Cotton alone	79	Cotton + Chilli + Pillipesara + Goat + Rabbit + Fodder	206	161	Vinodkumar et al. (2017)
17	Crop alone	155	Crop + goat + poultry + sheep + dairy	389	151	Solaiappan et al. (2007)
18	Rice- Wheat system	402	Rice-Wheat + Vegetable + Dairy + Fishery	760	89	Meena et al. (2013)
19	Rice alone	204	Rice + dairy + fish	555	172	Behera et al. (2013)
20	Rice-rice	400	Rice + fish + vegetables	899	125	Panda (2016)
21	Crop (1.5 Acre)	165	Crop + Bullocks + Cow + Buffalo + Goats + Poultry + Ducks	316	92	Rao et al. (2017)
22	crop alone	400	Crop + buffaloes	904	126	Pandey and Bhogal (1980)
23	Tuber crops	199	Tuber crops + vegetables + field crops + livestock	261	31	Shankar et al. (2018)
24	Tuber crops	203	Tuber crops + vegetables + field crops + livestock + aquaculture	263	30	Shankar et al. (2018)
Mean	Farmer's practice	255	IFS	497	143	

TABLE 3 Employment opportunities provided by integrated farming system

Probable areas	Job opportunities
Livestock and fodder component	• Caring for animals • Maintaining fodder block of forages, legumes and azolla unit
Organic farming	• Production of organic inputs such as vermicompost, compost • Post-harvest farm-to-market supply chains • Value addition to organic produce to increase the income
Agro-ecotoursim	• Linking tourism to traditional • farming landscapes • Developing herbal gardens, biodiversity park, fish farms, fish spa
Management of resources	• Rising nurseries to supply planting material • Participatory seed production to fetch higher market price • Planting diverse tree species and maintaining diverse economically important species

TABLE 4 Nutrient recycling potential of different integrated farming system (IFS) in India

Farming system	Nutrient recycling (kg)			References
	N	P_2O_5	K_2O	
Field crop + fish + cattle	235.7	192.7	225.2	Kumar et al. (2011)
Field crop + fish + duck + goat	110.4	58.7	68.1	
Crop + fish + poultry	192.5	119.7	77.8	
Cropping + Dairy + Fishery + Horticulture + Apiary	121.7	226.8	411.9	Singh et al. (2012)
Arecanut + Fodder + Dairy	218	51.8	33	Sujatha & Bhat (2010)
Crops + dairy + biogas + vermicomposting + fishery + horticulture + agroforestry-boundary plantation -Pantnagar	112.16	53.5	114.7	Ravisankar et al. (2016)
Crop + horticulture + dairy + vermicomposting + biogas + fishery-Kalyani	64	36	41	
Crops + Horticulture + Cattle + Fishery + Poultry + Apiary-Johrat	359.4	140	398.6	
Crop + Livestock (2 Cows) + Fishery cum duckery-Patna 0.8 ha	38.4	33.1	43	
Crop + Horticulture + Dairy + Sheep + Poultry	91	42	75	Goverdhan et al. (2020)
Crop + dairy + fish + poultry	55	17	76	Paramesh et al. (2021)

TABLE 5 GHG emission from different IFS models tested under AICRP-IFS

Location	Components	GHG emission (kg CO_2 eq. ha^{-1})
Palampur	Crops + Dairy + Horticulture + Fodder + vermi-compost + Boundary Plantations + Kitchen Gardening	−1787
Johrat	Crops + Dairy + Horticulture + Fishery + Poultry + Duckery + Goatery + Apiary + Vermi-compost + Biogas + Liquid Manure + FYM production	−3175
Kalyani	Crops + Dairy + Horticulture + Vermi-compost + Biogas + fishery	−4517
Raipur	Crops + Dairy + Horticulture + poultry + fishery + Goat + Mushroom + Vermicompost + Boundary Plantations + Kitchen Gardening	−7713
Telangana	Crops + livestock + hortipasture IFS model	−27036

Source: Ravisankar et al. (2019).

et al. (2000), Liu et al. (2007), and Schönbach et al. (2012). CH_4 absorption in IFS at Brazil was 68% lower than in conventional mono-cropping systems, and Chen et al. (2011) reported 30% lesser CH_4 absorption in IFS under temperate plains. The negative impact of IFS on CH_4 absorption may have been due to increased nutrient recycling in the

TABLE 6 Influence of legume inclusion on soil organic carbon change under integrated farming system of Kerala state, India

Farming System	Net area (ha)	Soil organic carbon (%) before inclusion of legumes	Soil organic carbon (%) After inclusion of legumes
Crop + Dairy + Horticulture	0.52	0.74	0.85
Crop + Dairy + Horticulture	0.22	0.68	0.79
Crop + Horticulture + Poultry + Fish	0.46	0.65	0.72
Crop + Dairy + Horticulture	0.34	0.75	0.78
Crop + Dairy + Horticulture + Fish	0.52	0.78	0.85
Crop + Dairy + Horticulture	0.44	0.75	0.78
Crop + Dairy + Horticulture	0.52	0.72	0.76
Crop + Dairy + Horticulture	0.42	0.68	0.77
Crop + Dairy + Horticulture	0.60	0.75	0.82
Crop + Dairy + Poultry	0.47	0.85	0.93
Crop + Dairy + Horticulture + Goat	0.46	0.64	0.76
Crop + Dairy + Horticulture	0.40	0.85	0.92
Crop + Dairy + Horticulture	0.36	0.60	0.68
Crop + Dairy + Horticulture	0.50	0.58	0.64
Crop + Dairy + Horticulture	0.50	0.90	0.93
Crop + Diary + Horticulture	0.40	0.88	0.92
Crop + Diary + Horticulture	0.57	0.92	0.95
Mean		0.75	0.82

Source: Ravisankar et al. (2019).

system through organic farming practices and may have further improved the abundance and activity of methanotrophs (Zhou et al., 2008) and possibly decreased air diffusion that could have impaired CH_4 diffusion (CHEN et al., 2011). So, the management practices such as nutrient management through composting and crop residues, and using legumes for nitrogen fixation, change in cultivation practices like direct seeded rice/SRI method of rice cultivation can increase the resilience of crops to changing climate and also reduces GHG emission. IFS is advocated as a promising strategy to increase agricultural production and rehabilitate degraded pastures while mitigating GHG emissions (Gil et al., 2015). Improved agronomic management and conservation of biodiversity lead to resilient, productive, and sustainable systems and can reduce environmental pollution. Bell et al. (2014) reported that combination of perennial forages with cropping, such as agroforestry, alley cropping, and intercropping, delivers different options for reducing the impact of climate change by improving carbon sequestration and nutrient availability.

Barbosa et al. (2015) observed IFS as a viable strategy to reduce GHG emissions and nutrient loss by better nutrient recycling and use of crop residues as animal feed. Sunderland (2011) opined that the addition of multipurpose trees to the farming system provides both food and income to the small and marginal holders and acts a source of livelihood and sequesters atmospheric carbon. Table 6 shows the importance of legume inclusion in the IFS system for enhancing soil organic carbon (%) and thereby improves soil carbon sequestration and soil microbial activity efficiently.

3.5 | Effect of integrated farming system on biodiversity conservation

The monoculture, for instance widespread adoption of rice–wheat, rice–rice, rice–maize system in irrigated agro-ecosystem of India affecting soil biology, causing genetic erosion, depleting groundwater availability, causing several environmental problems. Farmers choose crop diversity on small farms considering several factors, including increased nutrition, market diversification, and risk mitigation. Multi-enterprise schemes like IFS have potential to enhance ecological function through biodiversity restoration as well as expanded whole-system economic and agronomic productivity. Agricultural diversification occurs when a farm or agricultural community adds more plants, plant varieties, or animal breeds. The IFS promotes the growing of multiple crops together as intercrops, mixed crops, sequential crops, etc. (it may include annual, perennial crops, and tree crops) thereby provides ecosystem services from agriculture (nutrient recycling, improved

TABLE 7 Food and nutritional security provided by integrated farming system

Farming system (land Area)	Location and area of model	Cereals (Kg)	Pulses (Kg)	Oilseeds (Kg)	Milk (Liter)	Fruits (Kg)	Vegetables (Kg)	Eggs (nos.)	GF (Kg)	DF (Kg)	Mushroom (Kg)	Fuel wood (Kg)
Crops + Horticulture + Dairy + fish + Boundary Plantations	Modipuram−0.7	3040	282	363	4228	5560	2960	-	20940	4095	457	1194
Crops + Dairy + Horticulture + Goat + Vermicompost + Azolla + Boundary Plantations + Kitchen Gardening-	Siraguppa−1 ha	4959	289.9	44.88	1403	106	1740	-	5423	7281	-	114.2
Crops + Dairy + Horticulture + Fishery + Poultry + Duckery + Goatery + Apiary + Vermi-compost + Biogas	Jorhat−1 ha	2368	100	363	3600	270	1758	450	12180	3000	60	220
Crops + Dairy + Horticulture (fruits and vegetables)	Ludhiana−1 ha	3513	127	138	12635	487	5516	2500	19780	4966	38	-
Crops + Dairy + Goatry + Duckery + Vermicompost + boundary Plantations	Sabour- 1 ha	5220	135	140	3472	475	2065	1125	27800	7140	148	6.75
Crops + Dairy + Horticulture + Goat + poultry + Biocompost	Durgapur- 1.45 ha	1738	239	283	5902	162	1581	675	26560	3761	-	810

DF, Dry fodder; GF, Green fodder.

Source: Ravisankar et al. (2019).

soil quality, reduced economic losses due to crop failure, nitrogen fixation, water penetration, and pollination). IFS also stimulates soil microbial biodiversity through the addition of compost or manure or by duck droppings in rice–fish–duck culture. Nayak et al. (2018) observed structural variation in soil microbial diversity due to nutrient recycling (organic manures) with the production of planktons and macro-benthos in rice–fish–duck, rice–duck, and in rice–fish system over conventional rice production system. Like IFS encourages polycultures (annual, perennial crops, vegetables, flower crops, spice crops etc.) integration of livestock or fish with crops, including cover cropping, fodder production, and rotational grazing at the field scale. Thus resulting in heterogeneous landscapes complementary supports whole agrobiodiversity (including preferred biodiversity and related biodiversity) (Perfecto et al., 2005). The IFS also promotes non-crop biodiversity, first through ecological management strategies such as the use of minimal fertilizer and insecticides and then through the use of organic management practices. The addition of trees (fruit and timber trees) to the farming system able to provide both income and nutritional security to the farm family and also attracts honeybees, and other insects, in a broader set increases biodiversity, act as windshield, and adds aesthetic value to the farm (Sunderland, 2011). For example, due to climate change, the cultivation of irrigated rice, sugarcane, cotton, and other intensive crops in certain parts of India will become risky in the future. In such scenarios, growing drought-tolerant crops such as millets, short-duration pulses, vegetables, and root crops will become essential to achieve food security (Rufino et al., 2013). So, the IFS with multiple enterprises encourages biodiversity conservation, provides feed, fodder, and fuel, and also reduces risks associated with crop failure.

3.6 | Integrated farming system for food and nutritional security

The well-integrated complementary IFS systems provide dietary needs of farm families partially or fully from a small piece of land. Such systems form the future of the Indian agriculture system and help to provide most of the staples consumed by many millions of small and marginal farmers in India, as IFS offers scope to utilize land and time for growing short-duration vegetable crops, pulses, and fodder for livestock. These systems are very critical for achieving future food and nutrition for the burgeoning Indian population. The homestead farming integrated with the livestock component of Kerala, India, in an area of 0.2 ha supports a farm family of 4 members with vegetables, milk, and eggs throughout the year (John, 2014). Table 7 shows the potential of IFS in diversifying the food basket of small and marginal farmers from a small piece of land. The Table 7 also highlights the importance of IFS in producing fodder required for livestock and fuelwood for household consumption. Devendra and Thomass (2002) reported the importance of IFS for poor small and marginal farmers to meet the protein requirement through eggs, milk, and meat from the livestock component. The IFS might assist to achieve food and nutritional security through the better use of available resources, introduction of legumes, vegetables, oilseed crops, or through agroforestry systems (Altieri et al., 2012; Wezel et al., 2014). Further, understanding the complementary role of different components of IFS on small and marginal farmers is necessary to meet the food and nutritional requirement of the farm family (Ramanathan et al. 2020; Tittonell et al. 2005).

3.7 | Constraints in adoption of IFS

Despite several advantages, farmers are unable to adopt the IFS systems due to several constraints in different regions of the country. These constraints can be classified into different categories like financial, biophysical and sociocultural, institutional, or policy. However, the financial constraints (lack of required finance, high cost of inputs) emerged as major limitations in adopting crop-livestock integrated system at Madhya Pradesh (Pandey et al., 2019) due to high initial investment for the establishment of animal shed, purchase of livestock, etc. Further, biophysical constraints for adoption the IFS systems like non-availability of quality planting material, lack of skills and knowledge of new crops such fodder, and availability of veterinary service formed the major constraints in adopting the crop-livestock system at Salem District of Tamil Nadu (Pushpa, 2010). Moreover, sociocultural constraints viz., idiosyncratic character and attitude of the farmers is found as the major criteria in adopting an IFS system (Purnomo et al., 2021) in Indonesia, and farmers are resilient to change and found laggards in the adoption of new technology, improved crops, and livestock breeds. Nearly 30% of scheduled caste farmers at the surveyed location in Southern Karnataka, India, did not have a favorable attitude toward IFS adoption (Kumar & Narayanagowda, 2017). Hence, anchoring suitable motivation and encouraging through training and demonstration along with credit facilities and ensured supply of required quality planting materials, the farmer's attitude and adoption of integrated farming systems could be modified appropriately. Nevertheless, there is inadequate policy or institutional support for adoption of IFS in different agro-climatic regions of the country. As farming is very closely associated with the environment, it will have a greater impact on soil, water, landscape, and biodiversity. Hence, there is a need for region/location specific policy to provide crop specific price, insurance, and income support to insulate the farmers from market fluctuations and conserve the agro-ecological assets, maintain ecological balance through sustainable use of natural resources.

4 | CONCLUSION AND WAY FORWARD

The literature review revealed that IFS are important for efficient management of available resources at the farm level, to generate adequate income and employment for the rural poor, protection of the environment, and livelihood security. The synergistic interactions of the components of farming systems need to be exploited to enhance resource-use efficiency and recycling of farm by-products. As IFS relies more on farm resources and local resources for which IFS was found more sustainable and profitable, IFS provides scope to accommodate more crops, livestock, trees, honeybee, etc. for which the carbon sink in the system is more and more resilient to climate vagaries and can be a potential approach to mitigate climate change. Providing awareness about benefits of IFS to farmers, government policy, and subsidy support is essential to promote large-scale adoption of region specific IFS models.

We identified several limitations and opportunities to explore in the farming system research. First, the farming system research largely focused on important production outcomes for farmers, like yield and income enhancement. Therefore, the future research should also examine the relationships between land holding size and livelihoods for farmers and laborers. For example, IFS provides higher yields but lower absolute levels of marketable produce raises questions about the sustainability of their livelihoods. The small and marginal farm family should explore both agricultural and non-agricultural source of income (through value addition) to achieve sustainable livelihood. Second, there was a limited study on type of production and their associated environmental implications. Assessing particular farm sizes, type of enterprises, and recycling methods in the IFS would enable better identification of scale-specific relationships between farm size and environmental impacts. Finally, few studies have considered comprehensive ecosystem services provided by different type of IFS systems like homestead farming, agroforestry based, and livestock based. Future research should further investigate well-being for laborers, farmers, consumers, and their interaction with farm size and with other social and environmental outcomes.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

VP, VA, UKB, NR, AP, and ASP conceptualized the study. VP, DJ, TM, and MK reviewed and collected the data. VP, VA, RSR, and SR involved in formal analysis. VP, UKB, JG, SDM, VA, and NR involved in supervision and writing original draft.

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