




Crop + horticulture + livestock IFS model for ensuring food and livelihood security with improving profitability, employment, and climate resilience: a long term study in Telangana, India

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Abstract

The farming situation in Telangana, was specified as part of a long-term study that lasted eleven years, from 2011–12 to 2021–22, with the objective of holistically increasing livelihood, earnings, and employment creation through an IFS technique. Telangana located in the southern part of India, has 88.3% small and marginal farmers whose income could be increased through adoption of farming systems. System productivity, economics, energetics, sustainability indices, greenhouse gas emissions, employment generation along with food and nutritional security were evaluated to know the impact of integrated farming system on small and marginal farmers over the years. One ha area with a holistic integration of animals and crops and an average farmer's net income of ₹52,000 produced a total productivity of 31.4 t REY ha⁻¹ with a cost–benefit ratio of 1.58 and net profit of ₹183,123/- with total operational expense of ₹313,179/-. A total of 66.47% of the net income comes via crop-related profits, including those from feed, 5.09% from horticultural profits, and 24.23% out from livestock unit. Results indicates that IFS is a energy efficient model with higher employment generation and saves ₹87,752 through recycling which is a huge relief to the farmer. Net emissions of this system were of – 4243 kg CO₂ eq on average which indicates the sustainability of the system. The paper claims that crop–horticulture–livestock IFS model can secure the long-term viability of agricultural systems and enhance livelihoods of small and marginal farmer's.

Keywords Integrated farming system · Productivity · Profitability · Employment generation · Food and nutritional security

1 Introduction

Farmers have been primarily focusing on single-enterprise-based agricultural systems since the Green Revolution, which has resulted in declining productivity, deteriorating soil health, and an increasing chance of crop failure (Rahman & Sarkar, 2012). In developing

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nations like India, there is an increasing demand for animal-based foods in areas experiencing significant population increase, urbanization, and income growth. This is worsening the rivalry between cattle and crops (with more cropland being planted and fewer rangelands being used for rangeland). The necessity for a comprehensive approach to meeting the demands of an ever-growing population without upsetting the natural balance is urgent (Kumar et al., 2018a, 2018b). In comparison, small and marginal farmers in India only cultivate 44% of the nation's total arable land, yet they produce 86% of the nation's agricultural output (GOI, 2014). The average operating land holding size in 2010–2011 was 1.16 ha, and farm size has decreased further as a result of fragmentation (Kumar et al., 2018a, 2018b). The fragmentation of land resources poses a severe challenge to Indian agriculture's sustainability, food security, and financial viability (Siddeswaran et al., 2012). The production of crops based on cereals is the primary emphasis of India's small as well as marginalized farmers, who face significant risks from climatic anomalies like droughts and floods. Because of these anomalies, farmers cannot earn enough money to support their families (Kumar et al., 2018a, 2018b).

In order to sustain favorable and stable production conditions, substantial rates of external inputs are added to modern agricultural production systems, and they are logically simplified as a result of specialization (Karthik et al., 2022). These methods can be effective and productive, but they frequently have negative effects on the environment, deplete soil nutrients, alter soil biota, and increase production costs (Kashyap et al., 2022). Farming systems have found to be more productive as well as profitable compared to conventional systems. Layek et al. (2023) reported that crops + horticulture + cattle + piggery has recorded a system productivity of 21.92 tha^{-1} mainly because of integration of cropping systems and livestock whereas the traditional practice of maize-vegetables has recorded 8.59 t ha^{-1} at Meghalaya in India. Shyam et al. (2023) at New Delhi, India reported that integrated farming system has maximum gross as well as net returns were reported. of 18,268 and 9446 USD ha^{-1} with sustainable livelihood index (SLI) of 70.2% While traditional techniques for rice and wheat and maize have shown gross returns and net returns of 3159 & 1335 USD ha^{-1} with SLI of - 15.6% and 2712 & 1038 USD ha^{-1} with SLI of - 18.85%, respectively.

In India, intensive agriculture systems are unable to guarantee steady employment, income, and the availability of food, energy, and the environment. If a farmer solely engages in one form of agricultural enterprise, such as a traditional monocropping system, it might be challenging for them to make a living (Paramesh et al., 2021a, 2021b). Kumar et al. (2022) at Bihar, India reported that integrated farming systems have generated employment of 402 man-days year^{-1} in 2 acres area whereas rice-wheat system has generated employment of 237 man-days year^{-1} . Empirical pieces of evidence from different parts of the globe suggest that an integrated system is the most efficient in terms of energy efficiency (Alluvione et al., 2011) and it reduces the net GHG emissions thus making the system climate smart (Sahoo et al., 2020). Proper resource budgeting in integrated farming systems saves around 58% of the total cost of production through recycling and leads to greater resource use efficiency (Singh et al., 2018).

Maintaining food and nutritional security by integrating fisheries, cattle, along with crops, while giving farmers consistent and periodic revenue is essential for overcoming the limitations of specialised, input-driven agriculture (Gill et al., 2009; Kashyap et al., 2022; Paramesh et al., 2021a, 2021b). Regular cash flow is needed since it is impossible to support a farm family year-round on agricultural income; This is only achievable when the crop is associated with a sensible assortment of enterprises that are viable in the local context (Rana, 2015). Crop diversification is made possible through the Integrated Farming

System (IFS). The IFS quickly raises the income of farm families and aids in achieving agricultural sustainability. Incorporating more agricultural businesses will increase farm productivity and provide benefits for social, economic, environmental, and nutritional security (Mynavathi & Jayanthi, 2015). According to the Indian Council of Medical Research's (Reddy et al., 2020) recommendations, a family of five needs 110–125 kg of protein, 60 kg of oil, and 550–575 kg of carbohydrates annually. These requirements can be met by adhering to the IFS strategy.

Through initiatives including nutrient recycling, soil formation, improving soil fertility, and environmental performance, the IFS approach aims to decrease anthropogenic inputs while promoting ecological intensification and enhancing ecosystem functioning (Bell & Moore, 2012; Salton et al., 2014). IFS that are effectively managed are anticipated to be less risky as a result of business synergy, product diversity, and environmental reliability (Behera & France, 2016). The elements and businesses within the IFS differ from area to area based on agro-climatic factors, including water availability, land type, farmer socio-economic position, and consumer demand (Paramesh et al., 2021a, 2021b). Components need to be connected and work effectively together in order to create effective holistic farming systems (Bell & Moore, 2012). The Indian government expressed an interest in IFS's mixed farming systems for the advancement of the farming community, and as a result, several initiatives were developed to boost the output of cattle and agriculture while providing small and marginal farmers with a reliable source of income (Paramesh et al., 2021a, 2021b). The ideal IFS Model for Crops, Horticulture, and Livestock's have crucial components are depicted in Fig. 1.

India's region-specific IFS model would be crucial in satisfying this demand despite the complexity of the potential growth in food and nutritional consumption. Another difficulty is that the manufacturing strategy would have to be put into practice in the face of uncertainties and climate change. Developing a region based IFS models would help the farmers as well as country in this climate change era because it enhances the income, employment opportunities by parallely maintaining the sustainability. It reduces the GHG emissions with effective resource recycling and tackles the malnutrition problem



Fig. 1 Basic components present in the Crop–Horticulture–Livestock IFS Model

by providing food as well as nutritional security. The current long-term study was carried out with the intention of creating a model for effective resource usage in scenarios with limited irrigation to accomplish nutritional and food security, economics, climate—resilient, residue reuse, and employment creation for the farm family.

2 Materials and methods

2.1 Study area and description

Under the supervision of the ICAR-Indian Institute of Farming System Research (IIFSR), Modipuram, Meerut, the research was conducted at the primary on-station research centre at college farm, Professor Jayashankar Telangana State Agricultural University (PJTSAU) in southern Telangana zone, India. The goal of the Integrated Farming Systems research project, which ran from 2010 to 2011, was to create a model for an irrigated dry environment. The conditions of this study area represent the majority of Telangana farmers which is the reason for conducting experiment here. The property was designated for the development of a one-hectare farming model with components for horticulture, agriculture, and animal husbandry. The horticulture component comprised guava as a fruit crop and tomato, green pepper, and carrot intercrops as vegetables throughout the rainy season and *rabi* season, respectively. The crop component, which includes horticulture, fodder blocks, boundary plantation, and arable cropping systems such as rice-maize, rice-sunflower, maize-castor, maize + pigeonpea-cowpea, and pigeonpea + greengram-groundnut, was established and started in 2010. A unit of 20 backyard chicken birds (Vanaraja), 6 goats (Osmanabadi), and 2 dairy buffaloes (Murrah Breed) were started as the livestock component during the 2011 *kharif* season, and the full-fledged Integrated Farming Systems research has been going on ever since. However during 2017–18 the following modifications were implemented. The different components of proposed integrated farming system in On-Station IFS models from (2011–12 to 2021–22) was depicted in Table 1 and the an overview map of the study area and percent contribution of area under Crop–Horticulture–Livestock IFS Model shown in Figs. 2 and 3.

2.2 Technological interventions

On the basis of a constraint analysis and the requirements demands of various categories of farmers, innovative aim is to contribute on modules were developed and performed out on the field from 2011–12 to 2021–22. The farming system strategy, which considers household needs for food, fuel, and other necessities to ensure food and nutritional security while also boosting farm profits, was utilised to develop farm homes holistically. On-farm evaluation of an enhanced set of procedures together with the adoption of better varieties and capacity building was done for the sustainable development of farm households. To address the low yield brought on by an uneven fertiliser application and insufficient plant protection measures, both nutrition and pest control was implemented. The technical intervention utilised essential inputs like seeds, fertiliser, plant protection chemicals, etc. The interventions are listed in Table 2 component-by-component.

Table 1 Different components of proposed integrated farming system in On-Station IFS model from (2011–12 to 2021–22)

Modules/ Enterprises identified	Area (ha)	Model I (From 2011–12 to 2017–18)	Model II (From 2018–19 to 2021–22)
Crops/cropping systems	0.70		
	0.20	Rice-Maize & Rice-Castor	Rice-Groundnut
	0.10	Bt cotton + Greengram- Sorghum (Fodder)	Bt cotton + Greengram- Sorghum (Fodder)
	0.10	Maize–Groundnut	Maize–Groundnut -Sunhemp
	0.10	Pigeonpea + Sweet corn—Bajra	Pigeonpea + Sweet corn—Bajra
	0.10	Maize + Pigeonpea-Sunhemp (Fodder)	Maize + Pigeonpea—Sunhemp (Fodder)
	0.10	Hybrid Napier and Lucerne	Hybrid Napier
	0.20		
Horticulture			
	0.12	Fruit tree- Guava	Fruit tree- Guava
		Under storey Vegetables – 4	Under storey fodders
		Tomato, Clusterbean, Okra, Beetroot	Hedge lucerne
Livestock			
	0.07		
	0.04	Buffaloes -2 (Graded Murrah breed)	Desi Cows -2 (Gir breed)
	0.015	Goatery (Osmanabadi breed)	Sheep unit (Nellore Jodipi)
Supplementary units			
		Back yard Poultry	Poultry
		Vanaraja/Rajasri (40 H & 10 C)	Aseel (200 No.)
Recycling units (Complementary units)	0.010	Vermi-compost unit	Vermi-compost unit
	0.010	FYM	FYM
		Open heap method	Closed pit method
Supporting activities	0.025	Azolla production, Dwelling unit, tube-well, irrigation channels, store house etc.,	Kitchen garden, Biogas unit Azolla production, Dwelling unit, tube-well, irrigation channels, store house etc.,
Total	1.0		

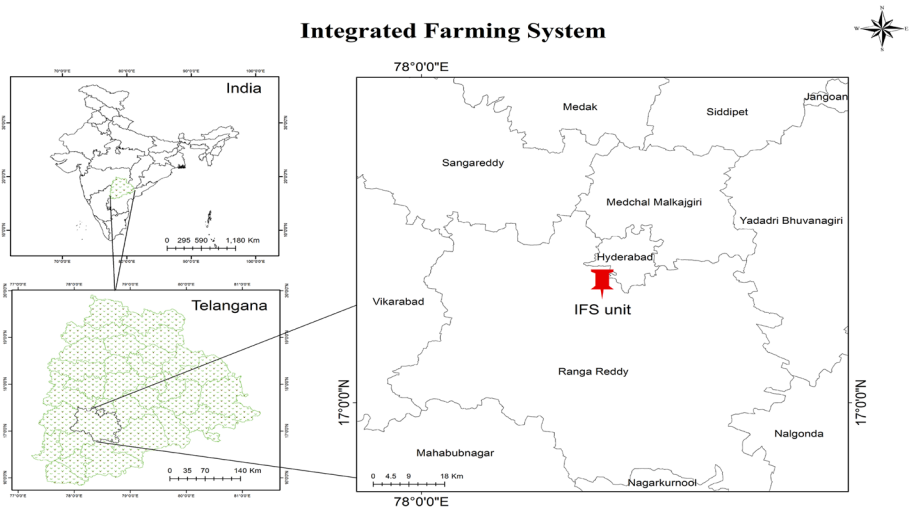


Fig. 2 An overview map of the study area

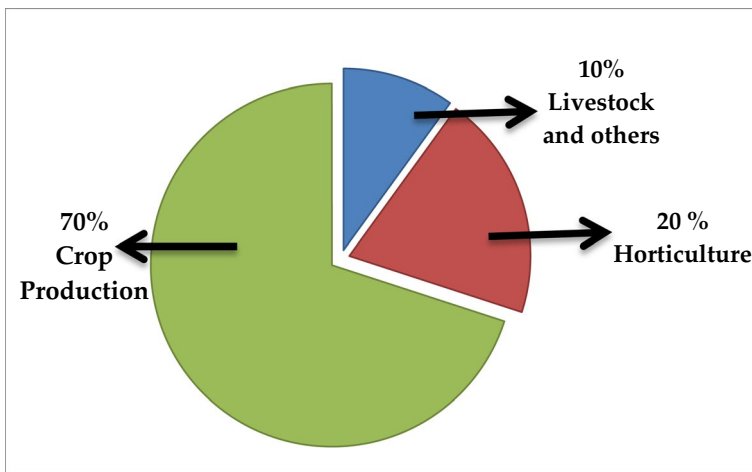


Fig. 3 Percent contribution of area under Crop-Horticulture-Livestock IFS Model

2.3 Energy input estimates (EI)

With the use of Eq. (1), energy input was determined.

$$EI = \left[\left\{ \sum (Es * s) \right\} + \left\{ \sum (Mm * tm) \right\} \right] / A \quad (1)$$

Es represents the total energy input as well as output components utilized in agricultural production of a particular crop, “s” is the energy equivalent coefficient for various energy input forms, and Mm is the energy equivalent in MJ h⁻¹ of the equipment, tm

Table 2 Modules wise technological interventions

IFS modules	Technological interventions
Crops and cropping techniques	Increased crop diversity and intensification Improved production technique includes things like HYV, intercropping, INM, IPM, and IWM The emphasis is on oil seeds and pulses
Livestock	Dairy cows lack nourishment and fertility Livestock vaccinations, deworming treatments, and calcium supplements The introduction of enhanced pig, goat, and poultry breeds Variety of agricultural practises for managing feed and fodder
Horticulture	Demonstration of the increased crop production bundle for vegetables Cultivating unusual crops to increase profits Cropping multiple tiers of vegetables and promoting a wholesome kitchen garden Low-cost polyhouse/nursery for growing vegetables off-season
Building secondary agriculture's capacity	Using both compost and vermicompost Modernized small farm machinery to lessen the drudgery of farm women Development of skills in nursery growing, on-farm processing, pruning, and appropriate agricultural methods (composting/vermicomposting) Visits to agricultural shows, KisanMelas, educational events, and exposure visits to IFS Distribution of literature in regional languages and provision of agro-risk advising services

denotes the machinery's or equipment's real operating time (h), and A denotes the entire cultivated area respectively.

2.4 Energy output estimates (EO)

With the use of Eq. (2), energy input was determined.

$$EO = \left[\left\{ \sum (P_{mc} * om) \right\} + \left\{ \sum (P_{bc} * ob) \right\} \right] / A \quad (2)$$

where EO stands for The output product's net energy content ($MJ ha^{-1}$), P_{mc} stands for total quantity produced by the principal crop (kg), P_{bc} stands for overall production amount of by-products (kg), "om" stands for net calorie content (NCV) of main crop as well as the by-products ($MJ kg^{-1}$), respectively, and A stands for the total area cultivated underneath a particular farming systems (ha).

2.5 Energy indicators

Using input energy in the form of human and animal energy usage of farm machinery and other equipment, fuel and gasoline consumption, production of fertilisers plus other agro-chemicals, utilization of organic manure and seed inputs, are the major energy indicators for the two cropping systems that are analyzed. The energy content (NCV) of the useful biomass (grains, straw, and tubers) plus the total volume of biomass created were utilized to calculate the output energy. The energy indicators are calculated using formulas that other researchers have used to carry out their own study. (Mittal & Dhawan, 1985; Muller & Sturm, 2001; Nassiri & Singh, 2009).

2.5.1 Energy use efficiency (EUE)

EUE calculates a crop production system's energy input and output efficiency, with the production of the primary crop and its byproducts serving as the output measure. One energy index that gauges how efficiently energy is used in agriculture is called EUE, and this ratio has been used to show how inefficient an agricultural production system is. The efficient use of energy for agriculture is shown by any rise in EUE, and vice versa.

$$EUE = \frac{\text{Total Output Energy (MJ ha}^{-1}\text{)}}{\text{Total Input Energy (MJ ha}^{-1}\text{)}} \quad (3)$$

2.5.2 Specific energy (SE)

In a cropping system, the energy required for generating a unit quantity of a crop is estimated by SE. A cropping system that is less efficient is represented by a higher SE value. The many strategies used to lower the SE all raise EUE, and vice versa. SE has been used extensively to compare various farm types.

$$SE \text{ (MJ kg}^{-1}\text{)} = \frac{\text{Total Input Energy (MJ ha}^{-1}\text{)}}{\text{Total main product yield (kg ha}^{-1}\text{)}} \quad (4)$$

2.6 Net return (NR)

The overall financial benefit to a farmer from a specific agricultural pattern is known as net return. One of the most significant measures of the farmer's economic outlook and agricultural profitability is this. It is estimated as the remaining income after all the production costs have been covered. There is an indication of the return on agricultural labor, management, and equity. It also accounts for any extra resources used in agriculture production that are not paid for in another way.

$$NetReturn(Rshayr^{-1}) = \frac{GrossIncome(Rshayr^{-1})}{\text{Total Annual Input Cost}(Rshayr^{-1})} \quad (5)$$

where the entire crop produced times its unit price equals the gross revenue, and total yearly input cost is the total of all fixed and variable expenses spent throughout the cultivation of crops across the two cropping systems.

2.7 Sustainability indices

Sustainability indices show how successful an agricultural system is. Adopting a variety of farming techniques might give farm households a sustainable source of income. The

sustainability of the businesses is guaranteed by the higher sustainability index ratings. Two indices were computed in this investigation.

The following formula, which was recommended by Singh et al. (1990), was used to generate the Sustainable Yield Index (SYI).

$$\text{Sustainable Yield Index (SYI)} = \frac{y - \sigma}{y \text{ max}} \quad (6)$$

where, y = average yield of a treatment over the years, σ = standard deviation (SD) and $y \text{ max}$ = observed maximum yield of a plot over the years.

Sustainable value index (SVI) was calculated by using following formula as suggested by Bohra and Kumar (2015)

$$\text{Sustainable Value Index (SVI)} = \frac{y - \sigma}{v \text{ max}} \quad (7)$$

where, y = average net profit over the years, σ = standard deviation (SD) and $v \text{ max}$ = maximum net profit obtain in any of the year.

2.8 Greenhouse gas emissions

The IFS-GHG Estimation Tool, created by the ICAR-Indian Institute of agricultural Systems Research, was used to calculate the greenhouse gas emissions from various agricultural system components (Subash et al., 2018). This program makes it possible to estimate greenhouse gas emissions from various components at the farm scale, from harvest to production. Considering the 100-year global warming potentials employed in national GHG accounting, the GHG emissions are presented in this tool as CO₂ equivalent per unit of crops and per head of animals (IPCC, 2006). Through seven input sections—each on a distinct Excel worksheet—related to crop, soil, inputs, fuel & energy consumption, irrigation, carbon, and transport—it simply gathers data on on-farm activities as determined while in the field. An estimate of the total greenhouse gas emissions in terms of carbon dioxide equivalents was obtained by appropriately feeding each section with inputs in accordance with certain plot circumstances.

2.9 Statistical analysis

Data on the production of different enterprises over a period of years was displayed year-by-year and on average within the appropriate parameters for two models (crop + horticulture + livestock). Both a descriptive and a qualitative analysis of the data were done. MS Excel was used to perform the descriptive average data analysis.

3 Results and discussion

3.1 Productivity and profitability

Pooled data of 2010–11 to 2016–17 indicated that the IFS model I was found to be sustainable with increased mean productivity of 31.40 t RGEY ha⁻¹ whereas Cost of production is ₹319,713 and gross & net returns were ₹442,365 and ₹122,653 year⁻¹, respectively. Pooled

Table 3 Productivity and profitability of IFS unit over eleven years (during 2010–11 to 2021–22)

IFS models	Years	Productivity (t RGEY ha ⁻¹ yr ⁻¹)	Cost of Production (Rs ha ⁻¹ yr ⁻¹)	Gross returns (Rs ha ⁻¹ yr ⁻¹)	Net returns (Rs ha ⁻¹ yr ⁻¹)	SYI (sustainable yield index)	SVI (Sustain- able value index)
Model I	2011–12	22.97	189,774	248,563	58,790		
	2012–13	20.25	268,267	314,302	46,035		
	2013–14	34.21	370,263	518,038	147,775		
	2014–15	32.31	332,607	439,411	106,805		
	2015–16	37.21	365,633	524,652	159,020	0.59	0.37
	2016–17	41.44	391,732	609,224	217,493	0.61	0.34
	Average	31.40	319,713	442,365	122,653	0.60	0.355
Model II	2017–18	33.32	302,766	516,396	213,631	0.77	0.58
	2018–19	36.42	348,796	646,566	297,770	0.79	0.56
	2019–20	31.64	288,547	589,156	300,609	0.78	0.74
	2020–21	28.00	287,315	512,442	225,127	0.70	0.77
	2021–22	27.85	299,270	540,573	241,303	0.76	0.72
	Average	31.45	305,339	561,027	255,688	0.76	0.67
	Overall mean	31.42	313,179	496,302	183,123	0.68	0.51

data of 2017–18 to 2021–22 indicated that IFS model II has obtained a productivity of 31.45 t RGEY ha⁻¹ with cost of production of Rs. 305,339 whereas gross & net returns were ₹561,027 and ₹255,688 year⁻¹, respectively (Table 3). Overall mean of 11 years data indicated that IFS system has obtained a productivity of 31.42 t RGEY ha⁻¹ with cost of production of ₹313,179 whereas gross & net returns were ₹496,302 and ₹183,123 year⁻¹, respectively. Livestock (59.07) and cropping unit (33.06) have played major role in obtaining higher productivity over the years. Multiple crops and livestock components helps to maintain the sustainability of the farm holdings. Swarnam et al. (2024) reported that livestock provides greater stability as it was less affected by climatic factors such as floods and water scarcity. IFS model I has obtained sustainable yield index and value index of 0.60 and 0.35, respectively whereas IFS model II has obtained sustainable yield and value index of 0.76 and 0.67, respectively (Table 3). 11 years data indicates that sustainable yield index and value index obtained were 0.68 and 0.51, respectively. Kumar et al. (2022) reported that average sustainability index of crops + fishery + dairy + goatery model and crops + fishery + goatery model were 0.77 and 0.65, respectively which is higher compared to conventional cropping system of rice–wheat and rice–maize which obtained 0.07 and 0.15, respectively in six years study which indicates component integration are sustainable in longer term in terms of productivity as well as profitability. Shyam et al. (2023) and Kumari et al. (2022) reported that judicious integration and synergism among enterprises and efficient by-product utilization making the enterprises self-sustainable by generating wealth from waste which makes the system self sustainable. He added that higher productivity and income leads to higher sustainability indices.

The higher profitability of IFS is mainly attributed to recycling of by-products which decreases the cost of production. Product diversification always benefits the farmers because one component covers the loss caused by another component. In our system, although dairy has incurred losses, net income is higher because of high productivity of cropping unit, goatery and poultry. According to Paramesh et al. (2022), IFS can increase farm profitability by 265% over the single enterprise by boosting net revenue. IFS could therefore be pushed as a means of support for Telangana's marginal and small-scale farmers. Suitable and viable IFS model for a region could be identified based on sustainability index which indicates economic viability as well as environmental friendliness. Integration of multiple components which are productive and profitable in nature would enhance the sustainability of a model.

3.2 Component wise contribution of different components

Component wise mean productivity of different units in IFS studied during 2011–12 to 2016–17 indicated that out of the IFS production costs on average (₹319,713) over years, 44.5% worth of inputs were obtained from the market, while 24.07 percent of those inputs were produced and recycled on the farm, further 31.42% of annual expenditure on labour engaged was met through family labour (Table 4). Pooled data of IFS model II indicated that out of the IFS production costs on average (₹305,346) over years, 46.53% worth of inputs were purchased from market and 34.47% of inputs were generated and recycled within farm, further 18.99% of annual expenditure on labour engaged was met through family labour during 2017–18 to 2021–22. Overall 11 years data indicated that out of the average cost of production of IFS (₹313,182) over years, Inputs total ₹142,200 (about 45.4%) were bought in the market, while ₹89,824 (approximately 28.7%) were produced

Table 4 Total Inputs cost and percent share of the inputs purchased/generated and recycled within the system

IFS models	Years	Total Input Cost (Rs.) (TIC)	Value of inputs purchased from market (Rs.)	Value of Inputs (Rs.) generated and recycled within farm	Number of farm Labour engaged, annual expenditure on it
Model I	2011–12	189,774	97,674 (51.47)	35,625 (18.7)	56,475 (29.76)
	2012–13	268,267	132,513 (49.40)	42,679 (15.91)	93,075 (34.69)
	2013–14	370,263	169,717 (45.84)	95,196 (25.71)	105,350 (28.45)
	2014–15	332,607	135,403 (40.71)	87,704 (26.37)	109,500 (32.92)
	2015–16	365,633	154,726 (42.32)	101,407 (27.73)	109,500 (29.95)
	2016–17	391,732	163,687 (41.78)	99,141 (25.31)	128,904 (32.91)
	Average	319,713	142,287 (44.50)	76,959 (24.07)	100,467 (31.42)
Model II	2017–18	302,766	137,632 (45.45)	70,765 (23.37)	94,369 (31.17)
	2018–19	348,796	156,378 (44.83)	125,626 (36.02)	66,792 (19.15)
	2019–20	288,582	132,339 (45.86)	126,642 (43.88)	29,601 (10.26)
	2020–21	287,315	144,474 (50.28)	92,368 (32.15)	50,474 (17.57)
	2021–22	299,270	139,662 (46.66)	110,906 (37.06)	48,703 (16.27)
	Average	305,346	142,097 (46.53)	105,261 (34.47)	57,988 (18.99)
	Overall mean	313,182	142,200 (45.4)	89,824 (28.7)	81,158 (25.9)

* Figures in parenthesis are percent share in total input cost

and recycled on the farm, further ₹ 81,158 (25.9%) of annual expenditure on labour engaged was met through family labour.

In IFS model I, ₹142,287 worth inputs were purchased from market on average whereas ₹76,959 worth inputs were recycled within the farm which saves around 24% cost of production. Labour cost accounts for the 31% of cost of production. In IFS model II, ₹142,097 worth inputs were purchased from market on average whereas ₹105,261 worth inputs were recycled within the farm which saves around 35% cost of production. Labour cost accounts for the 19% of cost of production (Table 4). Over all 11 years data indicates that ₹89,824 worth inputs were recycled within the farm which saves around 28% cost of production and labour cost accounts for 26% cost of production. Cost of production can be reduced through recycling of inputs in integrated farming system which will be a boon to a farmer.

3.3 Farm household nutrition and food security

Producing grains, pulses, oilseeds, fruits, vegetables, milk, meat, and fodder for cattle allows a farm family to have year-round nutritional, food, and fodder security on a single hectare of crop + livestock (dairy, goat, and poultry) + horticulture agricultural systems. A total productivity average of 31.40 t RGEY ha⁻¹ was achieved across the years under study, which covered the years 2011–12 to 2016–17 (Table 5). The system generated 2595 kg of cereals on average, 166 kg of pulses, 388 kg of oil seeds, 2301 L of milk, 95 kg of fruits, and 1157 kg of vegetables. The feed and fodder needs of a livestock unit with two cows or three buffaloes and three calves could also be satisfied by producing an average of 23,394 kg of green fodder and 4282 kg of dry fodder (Table 5). An average total productivity of 32.35 t RGEY ha⁻¹ was attained over the years under research, which included the years 2017–18 to 2020–21. On average, the system generated 2393 kg of cereals, 179 kg of pulses, 724 kg of oil seeds, 1055 L of milk, 265 kg of fruits, and 520 kg of vegetables. The needs of a livestock unit with two cows or three buffaloes and three calves might similarly be satisfied by producing an average of 42,823 kg of green fodder and 3034 kg of dry fodder (Table 5).

The average production over the course of 11 years was 2503 kg of cereals, 171 kg of pulses, 542 kg of oil seeds, 1639 L of milk, 162 kg of fruits, and 864 kg of vegetables, compared to the five-person farm family's annual demand of 730 kg of cereals, 125 kg of pulses, 120 kg of oil seeds, 400 L of milk, 120 kg of fruits, and 300 kg of vegetables (per Indian Council of Medical Research standards). The feed and fodder needs of a livestock unit with two cows/buffaloes and three calves might also be satisfied by producing an average of 31,214 kg of green fodder and 4138 kg of dry fodder annually as opposed to the demand of 17,500 kg of green fodder and 3000 kg of dry fodder. The annual protein (110–125 kg) plus carbohydrate (550–575) needs of a five-person family might be easily satisfied by an IFS system, according to Kashyap et al. (2022). According to Ray et al. (2020), the IFS model (crops + horticulture + fishery + piggery + poultry) produces enough meat (983%), eggs (27%), fruits (83%), vegetables (70%), and oilseeds (424%) for a family of five adults and two children. It also produces enough fruits and vegetables (83%), vegetables (70%), and oilseeds (424%). IFS effectively utilises time, location, and a variety of products to guarantee our nation's food security as well as dietary stability from a small piece of land. It satisfies the needs of a family of five members as well as livestock and the surplus produce is sold in the market for income generation and used for purchasing the deficit items. Meena et al. (2022) and Panwar et al. (2018) reported that having livestock components i.e., dairy, sheep, fishery or poultry in addition to cropping systems provides

Table 5 Demand and production of essential farm commodities to meet household food, feed and other daily meal requirements of an average family members (As per ICMR standards)

I/S models	Years	Cereals (kg)	Pulses (kg)	Oil seeds (kg)	Milk (l)	Fruits (kg)	Vegetables Incl. tubers (kg)	Green Fodder (kg)	Dry fodder (kg)	Others
Annual Demand of essential food and fodder commodities for a farm family with 5 family members and 2 buffaloes (On an average)										
		730	125	120	400	120	300	17,500	3000	–
Actual annual production of different farm commodities at farm										
Model I	2011–12	2873	121	365	2577	–	1019	9450	4470	FYM- 4387 kg VC-180 kg
	2012–13	2580	108	480	1748	–	1050	15,792	4497	FYM – 1356
	2013–14	2528	200	527	2428	33	1382	26,888	4287	FYM -9560 kg VC-2600 kg
	2014–15	2542	213.5	360	2580	40	1254	25,525	4266	FYM -12,512 kg VC-1572 kg
	2015–16	2434	156	295	2845	54	993	29,347	3791	FYM-16668 kg VC-1994 kg
	2016–17	2611	199	301	1629	254	1241	33,359	4381	FYM-16503 kg VC-2241 kg
	Average	2595	166	388	2301	95	1157	23,394	4282	15.39 t of FYM and 2.2 t of VC

Table 5 (continued)

IFS models	Years	Cereals (kg)	Pulses (kg)	Oil seeds (kg)	Milk (l)	Fruits (kg)	Vegetables Incl. tubers (kg)	Green Fodder (kg)	Dry fodder (kg)	Others
Annual Demand of essential food and fodder commodities for a farm family with 5 family members and 2 buffaloes (On an average)										
		730	125	120	400	120	300	17,500	3000	–
Actual annual production of different farm commodities at farm										
Model II	2017–18	2382	204	631	2411	234	416	37,636	2963	FYM-12780 kg VC-2172 kg
	2018–19	2298	180	710	1254	216	381	49,276	2918	FYM-11470 kg Biogas: 5 No cylinders LPG gas equivalent Biogas slurry: 1815 kg
	2019–20	2395	163	713	554	340	344	47,990	3057	FYM- 6918 kg Biogas: 7 No cylinders LPG gas equivalent Biogas slurry: 2910 kg
	2020–21	2497	168	840	0	269	939	36,389	3197	FYM- 10,214 kg Biogas: 3No cylinders LPG gas equivalent Biogas slurry: 1125 kg
	2021–22	2396	163	736	0	342	481	31,702	7691	FYM- 10,670 kg Vermicompost-315 kg
Average		2393	179	724	1055	265	520	40,599	3034	FYM- 10,345 kg and VC-2172 kg Biogas: 5 No cylinders LPG gas equivalent Biogas slurry: 1950 kg
Overall mean		2503	171	542	1639	162	864	31,996	4138	

household nutritional security and also enhances the availability of these products in the market.

3.4 Employment generation in IFS

The system also offered the chance to engage farm family labour, which resulted in an average employment generation of 809 man days from 2011–12 to 2016–17. The livestock unit generated the most employment on average, 513 man days (63.35%) in the dairy industry, followed by 125 man days (15.45%) in the goatery and poultry sectors. On average, a cropping unit provided 117 man days of employment (Table 6). Also because livestock unit requires ongoing care throughout the year, employment was available even during the lean season. From 2017–18 to 2021–22, 538 man days of employment were generated on average, and using farm families as labour allowed for annual labour wage savings of about ₹58,628. In the livestock unit, 190 man days (36.32%) were generated by the dairy sector, 176 man days (33.65%) by the sheep and poultry sectors, and 190 man days (36.32%) by the dairy sector. An average agricultural unit employed 121 man days per year (Table 6).

The method also gave the chance to engage farm families in labour, which allowed for an annual labour wage savings of about ₹81,158 and an average employment generation of 679 man days between 2011–12 and 2021–22. The livestock unit generated the most employment on average, with 366 man days (53.9%) going to the dairy industry, followed by 148 man days (21.79%) to the goatery and poultry industries. On average, 119 (17.5%) man days were employed by cropping units. Since the livestock unit requires ongoing care throughout the year, employment was available even during the lean season. IFS generate more jobs as compared to conventional cropping system which is mainly because of more number of enterprises and their maintenance. By using family labour, which is valued highly in IFS, the cost of cultivation can be decreased. Both Kumar et al., (2018a, 2018b) and Goverdhan et al. (2020) reported results that were comparable. Similar findings were made by Purnomo et al. (2021), who indicated that including one or more crop varieties or adding animals, fish, or birds to crops increased the required man-days by 43% to 55%. The problem of labour migration from rural area to urban areas can be solved through practicing IFS as creates employment throughout the year and rural youth might take up the IFS as an entrepreneurship venture.

3.5 Energy budgeting

The farming system is a method for managing resources to get the most out of a certain system. Energy usage in integrated farms is significantly lower than in conventional farms since they are generally less automated and promote the employing of internal inputs (instead of utilizing external farm inputs like fertilizers) (Dasgupta et al., 2015). Average energy input of the IFS model I is 328,586 MJ with which it has produced 387,580 MJ. The average energy use efficiency of the IFS system is 1.21, with net energy gain of 58,994 MJ, energy profitability of 0.21 and required 5.91 MJ to produce a kg of produce. Average energy input of the IFS model II is 376,090 MJ with which it has produced 499,264 MJ (Table 7). The average energy use efficiency of the IFS system is 1.37, with net energy gain of 123,174 MJ, energy profitability of 0.35 and required 11.06 MJ to produce a kg of produce. 11 years data indicated that average energy input of the systems is 350,179 MJ with which it has produced 438,345 MJ. The average energy use efficiency of the IFS system is

Table 6 Employment generation in IFS Unit over years

IFS models	Years	Total IFS	Cropping unit	Livestock unit		Horticulture unit	Recycling unit	Kitchen garden
				Dairy	Goatery/sheep & poultry			
Model I	2011–12	645	119 (18.45)	376.5 (58.37)	95.2 (14.76)	34 (5.27)	20.00 (3.10)	
	2012–13	842	117 (13.90)	547.5 (65.02)	121.6 (14.44)	34 (4.04)	22.00 (2.61)	
	2013–14	834	110 (13.19)	547.5 (65.65)	121.6 (14.58)	33 (3.96)	21.75 (2.61)	
	2014–15	829	110 (13.27)	547.5 (66.04)	114.8 (13.85)	32 (3.86)	24.25 (2.93)	
	2015–16	877	128 (14.58)	547.5 (62.36)	146.0 (16.63)	32 (3.67)	24.25 (2.76)	
	2016–17	829.5	116 (13.98)	509.5 (61.42)	153 (18.44)	27 (3.25)	24 (2.89)	
	Average	809	117 (14.46)	512.5 (63.35)	125 (15.45)	32 (3.96)	22.50 (2.78)	
Model II	2017–18	639.5	109 (17.04)	365 (57.0)	119.5 (18.60)	14 (2.18)	24 (3.75)	8 (1.25)
	2018–19	602	114 (18.93)	255 (42.35)	189 (31.39)	16 (2.65)	19 (3.15)	9 (1.49)
	2019–20	447	113 (25.27)	109 (24.38)	190.5 (42.62)	10 (2.24)	16 (3.58)	8 (1.79)
	2020–21	461	125 (27.11)	109.5 (23.75)	191.5 (41.54)	12.5 (2.71)	14 (3.03)	8 (1.73)
	2021–22	464.5	143 (30.78)	109.5 (23.57)	188.5 (40.58)	15.5 (3.33)	4 (0.86)	4 (0.86)
	Average	523	121 (23.13)	190 (36.32)	176 (33.65)	14 (2.67)	13 (2.48)	7 (1.33)
	Overall mean	679	119 (17.5)	366 (53.9)	148 (21.79)	21 (3.0)	19 (2.7)	7 (1)

* Figures in parenthesis are percent share in total man days

Table 7 Energy budgeting in IFS unit over eleven years (during 2010–11 to 2021–22)

IFS models	Years	Energy input (MJ)	Energy output(MJ)	Energy use efficiency	Net energy gain (MJ)	Energy profit-ability	Specific energy (MJ/kg)
Model I	2011–12	185,817.6	281,374.4	1.51	95,556.8	0.51	4.36
	2012–13	281,206.3	328,723.0	1.17	47,516.7	0.17	3.51
	2013–14	428,165.0	445,042.4	1.04	16,877.5	0.04	7.78
	2014–15	323,928.5	411,319.6	1.27	87,391.1	0.27	8.10
	2015–16	370,946.8	408,400.7	1.10	37,453.9	0.10	4.49
	2016–17	381,453.3	450,622.0	1.18	69,168.6	0.18	7.19
	Average	328,586	387,580	1.21	58,994	0.21	5.91
Model II	2017–18	250,570.8	472,039.9	1.88	221,469.0	0.88	7.39
	2018–19	455,948.3	543,057.3	1.19	87,109.0	0.19	12.78
	2019–20	421,317.3	550,599.6	1.31	129,282.2	0.31	7.77
	2020–21	346,808.9	456,940.1	1.32	110,131.2	0.32	12.8
	2021–22	405,804	473,681	1.17	67,877	0.07	14.57
	Average	376,090	499,264	1.37	123,174	0.35	11.06
	Overall mean	350,179	438,345	1.29	88,167	0.28	8.25

1.29, with net energy gain of 88,167 MJ, energy profitability of 0.28 and required 8.25 MJ to produce a kg of produce which indicates integrated farming systems as energy efficient. These findings concur with those of Pasha et al. (2020) and Kumar et al. (2019).

It is suggested to use precision agriculture, improved irrigation technology, and additional organic fertilizers to raise the energy consumption efficiency of the IFS model (Jackson et al., 2010; Mohammadi et al., 2014). Agriculture has become energy intensive these days because of soaring demand for food, feed and fuel. But it is not sustainable as climate crisis is knocking our door which implies the need of energy efficient farming. Our system is energy efficient which could be well recommended to the farmers.

3.6 Livelihood analysis

Meeting the needs of farm family is the essential criteria for selecting components for integrated farming system. Sujatha and Bhat (2015) emphasized the need to meet dietary requirements *i.e.*, cereals, pulses, eggs, milk, meat and fish in an integrated farming system of small and marginal farmers. Adoption of integrated farming system provides the livelihood security and results in higher family savings after fulfilling the needs of a family and livestock. The Crop + Livestock + Hortipastoral integrated farming system produces a total family saving of ₹139,273 (Average of 7 years), which has included family labour wages worth ₹80,411. This is according to a livelihood study of the system. In order to satisfy the needs of the family, this produced marketable surplus of ₹371,982, or ₹92,813 with an expected family size of 2 + 3 (Table 8). The IFS model generated a notably increased marketable excess of specific food commodities, resulting in favorable returns and cash reserves. These findings concur with Fatima et al. (2021) who revealed that IFS model (1 ha) of crop + dairy + fishery + poultry + duckery has obtained family savings of ₹214,000 which is very high as compared to family savings of ₹33,000 obtained in conventional rice–wheat cropping system.

3.7 Resource recycling in IFS

By effectively recycling crop and animal waste that has been generated within the integrated system, integrated farming systems help to reduce the use of inorganic chemicals and agrochemicals that are purchased from outside sources. This lowers the cost of external inputs and reduces the toxicity risks to soil, air, and water. 11.83 tonnes of FYM, 0.18 tonnes of Vermicompost, 4.10 tonnes of goat manure, 0.13 tonnes of poultry manure were recycled annually from 2011–12 to 2016–17 which saves around Rs. 73,262 and reduces the dependence on off farm inputs. Data from 2017–18 to 2021–22 indicates that 10.42 tonnes of FYM, 0.50 tonnes of Vermicompost, 3.57 tonnes of goat manure, 0.24 tonnes of poultry manure were recycled annually which saves around Rs.105193 (Table 9). Over the 11 years data indicates that that 11.19 tonnes of FYM, 1.00 tonnes of Vermicompost, 3.86 tonnes of goat manure, 0.18 tonnes of poultry manure were recycled annually which saves around ₹87,752 which is a huge relief to the farmer. Cost of production could be reduced through recycling of residues in integrated farming system. It provides good opportunity for recycling crop wastes and byproducts to livestock, and livestock waste can be employed as beneficial manure in agricultural endeavours. When waste from one component is recycled and used as input by another, the IFS can reduce production costs. It can also reduce the number of external inputs required. Proper resource budgeting in integrated farming approach reduces the total cost of production through recycling and also leads to higher

Table 8 Livelihood analysis of IFS model

Years	Value of all the farm commodities produced (A)	Value of farm commodities consumed in family (B)	Value of farm commodities recycled within the system (C)	Marketable surplus (A-B-C)=D	Cost of production (E)	Family savings (F=(D-E))	Family labour wages (G)	Total family saving (F+G)
	(Rs.)	(Rs.)	(Rs.)	(Rs.)	(Rs.)	(Rs.)	(Rs.)	(Rs.)
2015–16	524,655	55,525	103,324	365,805	365,633	173	109,500	109,673
2016–17	609,232	64,179	104,073	440,980	391,732	49,249	128,904	178,153
2017–18	507,481	63,921	101,327	342,233	397,878	17,036	128,904	145,940
2018–19	646,566	90,202	142,831	413,533	348,301	112,713	66,792	179,505
2019–20	587,563	94,547	110,316	382,920	288,547	161,043	29,601	190,644
2020–21	512,442	89,106	107,635	315,701	287,315	28,386	50,474	78,860
2021–22	540,573	92,813	105,058	342,702	299,270	43,432	48,703	92,135
Mean	561,216	78,613	110,652	371,982	339,811	58,862	80,411	139,273

Table 9 Residue recycling of IFS model

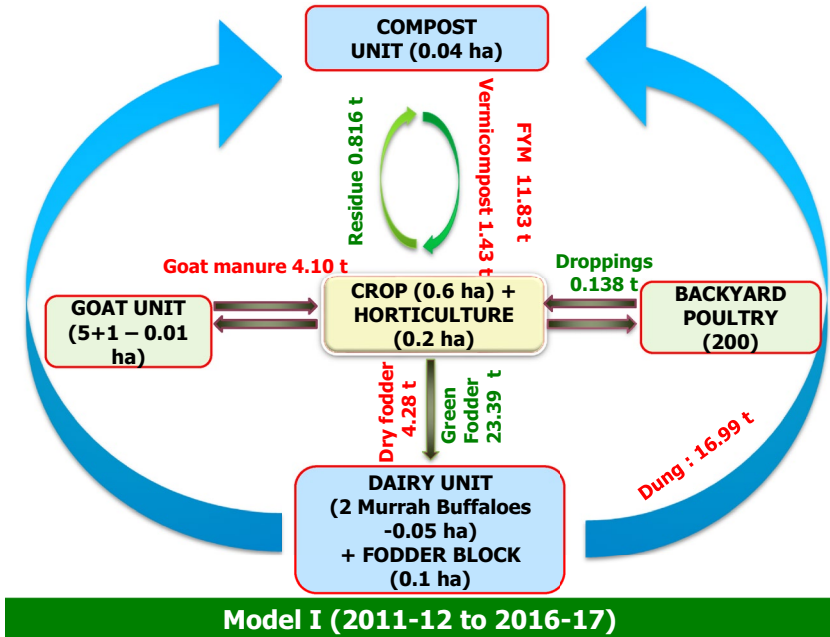
IFS models	Years	FYM (t)	VC (t)	Goat/sheep manure (t)	Poultry manure (t)	Value of purchased inputs (Rs)	Value of recycled inputs (Rs)
Model I	2011–12	4.39	0.18	0.48	0.30	97,674	35,625
	2012–13	11.36	–	1.83	0.23	132,513	42,679
	2013–14	9.56	2.60	4.31	0.11	169,717	95,196
	2014–15	12.51	1.57	4.65	–	135,403	87,704
	2015–16	16.67	2.00	6.65	–	154,726	101,407
	2016–17	16.50	2.24	6.71	0.14	163,687	76,959
	Average	11.83	1.43	4.10	0.13	142,287	73,262
Model II	2017–18	12.80	2.17	2.33	0.25	137,632	70,765
	2018–19	11.50	–	2.64	0.23	156,378	125,626
	2019–20	6.92	–	4.13	0.27	132,339	126,642
	2020–21	10.21	–	4.43	0.21	144,474	92,638
	2021–22	10.67	0.31	4.32	0.25	139,662	110,296
	Average	10.42	0.50	3.57	0.24	142,097	105,193
	Overall mean	11.19	1.00	3.86	0.18	142,200	87,752

resource use efficiency. When cattle, fisheries, etc. were integrated with crops, Sujatha and Bhat (2015) showed improved nutrient usage efficiency, recycling of nutrients, with greater soil microbial activity.

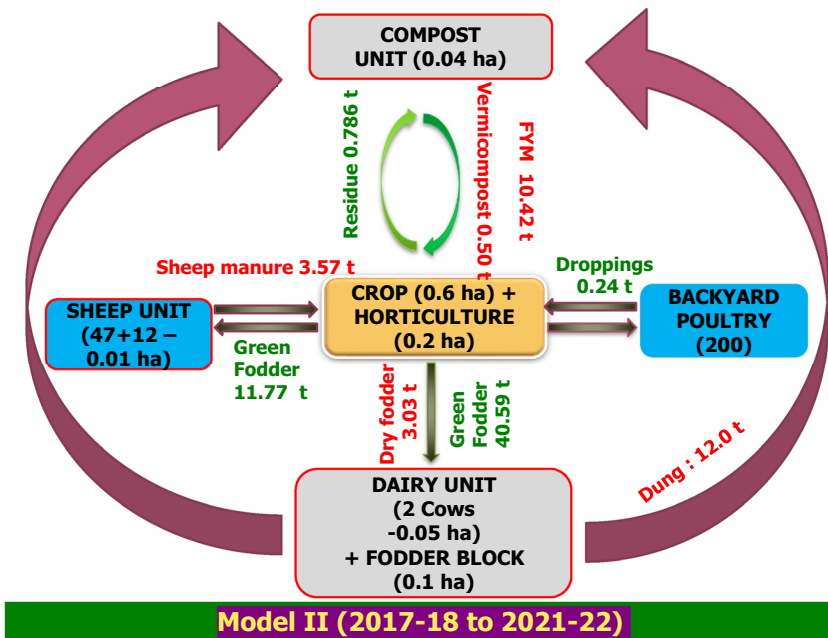
In IFS model I, 11.83t of FYM and 1.43t of vermicompost were recycled annually from crop residues and 4.1 t of goat manure, 138 kg of poultry droppings were recycled annually as manures and applied in the field which saves fertilizer cost. Main problem in livestock rising is fodder availability and price which can be encountered by cultivation of fodder crops in the field which is possible in integrated farming system. 23.39 t of green fodder and 4.28 t of dry fodder were produced annually which is sufficient for the dairy and goatery unit (Fig. 4a). In IFS model II, 10.42 t of FYM and 500 KG of vermicompost were recycled annually from crop residues and 3.57 t of sheep manure, 240 kg of poultry droppings were recycled annually as manures and applied in the field which saves fertilizer cost. According to Kumar et al. (2022), using organic manure—such as vermicompost, FYM, and the manures of sheep and poultry—received through resource recycling improved crop output and decreased cultivation costs by preserving a sizable amount of fertilizer. Main problem in livestock rising is fodder availability and price which can be encountered by cultivation of fodder crops in the field which is possible in integrated farming system. 40.59 t of green fodder and 3.03 t of dry fodder were produced annually which is sufficient for the dairy and sheep unit (Fig. 4b). According to Paramesh et al., (2021a, 2021b), the melding of crops and animals can improve the cycling of residues and nutrients and the sustainable use of existing resources.

3.8 Greenhouse gas emissions:

The critical need is to find sustainable farming methods to combat climate change. One of the finest methods for reducing greenhouse gas emissions in a sustainable way is integrated



(a)



(b)

Fig. 4 Residue recycling in Crop+ Horticulture+ livestock farming system in 1 ha area over the years for ID situations of Telangana state

Table 10 GHG emissions of integrated farming system over the eleven years (2011–12 to 2021–22)

IFS models	Year	Source (kg CO ₂ eq)	Sink (kg CO ₂ eq)	Net emissions (kg CO ₂ eq)
Model I	2011–12	4724	5535	– 811
	2012–13	6154	6988	– 834
	2013–14	7044	9480	– 2436
	2014–15	7048	9040	– 1992
	2015–16	7503	13,571	– 6068
	2016–17	7388	12,031	– 4643
	Average	6644	9441	– 2797
Model II	2017–18	5305	12,737	– 7432
	2018–19	5284	8133	– 2849
	2019–20	4863	8591	– 3728
	2020–21	8185	16,002	– 7816
	2021–22	10,884	18,947	–8063
	Average	6904	12,882	– 5978
	Overall mean	6762	11,005	– 4243
Standard deviation	1804.29	4062.04	2737.88	

farming systems. IFS has a great deal of potential for storing carbon in the ecosystem because (a) trees are regarded as essential elements, (b) Raising animals and using organic manures often improve soil carbon storage; (c) minimizing external inputs such as fertilizers helps to indirectly save fossil fuel; and (d) using minimal fossil fuel in farming. Total GHG emissions of each component in terms of equivalents of carbon dioxide emissions were calculated to obtain the net emissions. Overall negative net greenhouse gas emissions were recorded because of trees, organic manures and reduction in the usage of fossil fuels. Crops with higher biomass production offset the GHG emissions by livestock components which results in negative net GHG emissions of IFS and these diverse components act as insurance against climate change.. According to Meena et al. (2022), increasing agricultural and livestock intensification boosts the carbon sink, making the IFS model less harmful to the environment. IFS model I had net emissions of – 811 kg CO₂ eq, which showed the system's sustainability. On average, the model released 6644 kg CO₂ eq and absorbed 9441 kg CO₂ eq. The average CO₂ equivalent (kg) released and absorbed by the IFS model II was 6904 kg and 12,882 kg, respectively, for a net CO₂ equivalent (kg) of -5978 kg (Table 10).

The IFS system has released an average of 6762 kg of carbon dioxide over the course of the past 11 years, while also absorbing 11,005 kg of carbon dioxide. This results in net emissions of -4243 kg of carbon dioxide, which shows the system's sustainability. Leguminous crops were added to the system, and this led to fewer emissions than those from millet or other cereals. Rice enhances the methane emissions which could be balanced by adding livestock and fodder components. Twine (2021) and Pasha et al. (2020) reported that the best option for reducing GHG emissions that contributes to environmental sustainability is to integrate livestock with crop production because the energy input required it took a lot of cattle to generate a given amount of livestock goods, and it was predicted that the livestock would contribute more greenhouse gas emissions than the crops.

4 Conclusion

Majority of Indian farmers are small and marginal who have low access to advanced technologies and machinery and less investment capacity and they practice single enterprise farming which fails to provide sufficient income. The paper concludes that for small and marginal farmers, the path to long-term stable income, employment, means of subsistence, and nutritional security lies in the integrated agricultural system, which is an efficient instrument. The IFS model for crops, horticulture, and livestock had the best overall resource integration and would increase a farmer's revenue by two times while also maintaining productivity. A sustainable integrated farming system offers the highest return, and reduce GHG emissions that contributes to environmental sustainability. It enhances working opportunities by creating employment throughout the year and enhances energy use efficiency by using minimal inputs which creates more energy. By-products and waste from one system component were used as inputs for another, reducing the need for off-farm inputs and enhancing sustainability. It is clear that by successfully recycling wastes and maintaining food, fodder, economic, and eventually social security, small and marginal farmers gain from implementing the unified agricultural system idea.

4.1 Future line of work

Future studies shall be focused on the complete stall feeding of animals with various feed rations, usage of artificial intelligence for assessment of livestock health and machinery for livestock milking and cutting.

Author contributions This work was carried out in collaboration among all authors. This research paper has prepared by the author MVR under conceptualization, direct supervision and guidelines of the author's ChPK, MG and SS for writing—original draft. The author's GK, KS and MSC was extensively involved in project administration, supervision, formal analysis and editing the original draft of this paper, whereas the author's RK, MSK and NR kept contribution in verifying and finalizing the manuscript. All authors have read and agreed to the final version of the manuscript.

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Informed consent Not applicable.

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References

Alluvione, F., Moretti, B., Sacco, D., & Grignani, C. (2011). Energy use efficiency of cropping systems for a sustainable agriculture. *Energy*, 36(7), 4468–4481.

- Behera, U. K., & France, J. (2016). Integrated farming systems and the livelihood security of small and marginal farmers in India and other developing countries. *Advances in Agronomy*, 138, 235–282.
- Bell, L. W., & Moore, A. D. (2012). Integrated crop–livestock systems in Australian agriculture: Trends, drivers and implications. *Agricultural Systems*, 1(111), 1–2.
- Bohra, J. S., & Kumar, R. (2015). Effect of crop establishment methods on productivity, profitability and energetics of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) system. *Indian Journal of Agricultural Sciences*, 85(2), 217–223.
- Dasgupta, P., Goswami, R., Ali, M., Chakraborty, S., & Saha, S. (2015). Multifunctional role of integrated farming system in developing countries. *International Journal of Bio-Resource and Stress Management*, 6(3), 424–432.
- Fatima, A., Singh, V.K., Rathore, S.S., Singh, R.K., & Upadhyay, P.K. (2021). Livelihood analysis of different integrated farming system models under North-West India. *Extended Summaries: 5th International Agronomy Congress*, November 23–27, 2021, India.
- Gill, M. S., Singh, J. P., & Gangwar, K. S. (2009). Integrated farming system and agriculture sustainability. *Indian Journal of Agronomy*, 54(2), 128–139.
- GOI. (2014). *Agricultural statistics at a glance*. Directorate of economics and statistics. New Delhi: Govt of India.
- Goverdhan, M., Kumari, C. P., Reddy, G. K., Sridevi, S., Alibaba, M. D., Chiranjeevi, K., & Kumar, M. S. (2020). Evaluation of integrated farming system model for resource recycling and livelihood security of small and marginal farmers of Telangana State, India. *Current Journal of Applied Science and Technology*, 39(34), 17–26.
- IPCC. (2006). IPCC guidelines for national greenhouse Gas inventories—2006, prepared by the national greenhouse Gas inventories programme. In H. S. Eggleston, L. Buendia, K. Miwa, T. Ngara, & K. Tanabe (Eds.), *Intergovernmental panel on climate change* (pp. 1–20). IPCC/IGES.
- Jackson, T. M., Khan, S., & Hafeez, M. (2010). A comparative analysis of water application and energy consumption at the irrigated field level. *Agricultural Water Management*, 97, 1477–1485.
- Karthik, R., Dhaker, D., & Raising, L. (2022). Performance of cereals under need based nitrogen management strategies: A review. *Agricultural Reviews*, 43(3), 320–326.
- Kashyap, P., Prusty, A. K., Panwar, A. S., Paramesh, V., Natesan, R., Shamim, M., Verma, N., Jat, P. C., & Singh, M. P. (2022). Achieving food and livelihood security and enhancing profitability through an integrated farming system approach: A case study from western plains of Uttar Pradesh India. *Sustainability*, 14, 6653.
- Kumar, S., Shivani, Dey, A., Kumar, U., Kumar, R., Mondal, S., Kumar, A., & Manibhushan. (2022). Location-specific integrated farming system models for resource recycling and livelihood security for smallholders. *Frontiers in Agronomy*, 75–90.
- Kumar, R., Patra, M. K., Thirugnanavel, A., Deka, B. C., Chatterjee, D., Borah, T. R., Rajesha, G., Talang, H. D., Ray, S. K., Kumar, M., & Upadhyay, P. K. (2018a). Comparative evaluation of different integrated farming system models for small and marginal farmers under the eastern Himalayas. *Indian Journal of Agricultural Sciences*, 88(11), 1722–1729.
- Kumar, R., Patra, M. K., Thirugnanavel, A., Deka, B. C., Chatterjee, D., Borah, T. R., Rajesha, G., Talang, H. D., Ray, S. K., Kumar, M., & Upadhyay, P. K. (2018b). Comparative evaluation of different integrated farming system models for small and marginal farmers under the Eastern Himalayas. *Indian Journal of Agricultural Sciences*, 88(11), 1722–1729.
- Kumar, S., Kumar, R., & Dey, A. (2019). Energy budgeting of crop–livestock–poultry integrated farming system in irrigated ecologies of eastern India. *Indian Journal of Agricultural Sciences*, 89(6), 1017–1022.
- Kumari, Ch. P., Venkata Ramana, M., Goverdhan, M., Kiran Reddy, G., Vinay, G., Santhosh Kumar, M., & Karthik, R. (2022). Cropping system diversification for various integrated farming system models in Telangana. *Biological Forum—an International Journal*, 14(1), 1432–1438.
- Layek, J., Das, A., Ansari, M. A., Mishra, V. K., Rangappa, K., Ravisankar, N., Patra, S., Baiswar, P., Ramesh, T., Hazarika, S., Panwar, A. S., Devi, S., Ansari, M. H., & Paramanik, B. (2023). An integrated organic farming system: Innovations for farm diversification, sustainability, and livelihood improvement of hill farmers. *Frontiers in Sustainable Food Systems*, 7, 1151113.
- Manjunath, B. L., Paramesh, V., Mahajan, G. R., Reddy, K. V., Das, B., & Singh, N. P. (2018). A five years study on the selection of rice based cropping systems in Goa, for west coast region of India. *Journal of Environmental Biology*, 39, 393–399.
- Meena, L. R., Kochedaw, S. A., Prusty, A. K., Bhanu, C., Kumar, S., Meena, A. L., Meena, L. K., Raghavendra, K. J., Kumar, D., Subash, N., & Singh, S. P. (2022). Sustainable integrated farming system model for small farm holders of Uttar Pradesh. *Indian Journal of Agricultural Sciences*, 92(9), 1080–1085.


- Mittal, V. K., & Dhawan, K. (1985). Research digest on energy requirements in agricultural sector (Technical Bulletin No. ICAR/AICPP/ERAS/85-1). Punjab Agricultural University, Punjab, India.
- Mohammadi, A., Rafiee, S., Jafari, A., Keyhani, A., Mousavi-Avval, S. H., & Nonhebel, S. (2014). Energy use efficiency and greenhouse gas emissions of farming systems in north Iran. *Renewable and Sustainable Energy Reviews*, *30*, 724–733.
- Muller, K., & Sturm, A. (2001). *Standardized eco-efficiency indicators*. Switzerland, Ellipsen: A concept paper.
- Mynavathi, V. S., & Jayanthi, C. (2015). Dry land integrated farming system—A review. *Agricultural Review*, *36*(1), 67–72.
- Nassiri, S. M., & Singh, S. (2009). Study on energy use efficiency for paddy crop using data envelopment analysis (DEA) technique. *Applied Energy*, *86*, 1320–1325.
- Panwar, A. S., Ravisankar, N., Shamim, M., & Prusty, A. K. (2018). Integrated farming systems: A viable option for doubling farm income of small and marginal farmers. *Bulletin of the Indian Society of Soil Science*, *32*, 68–88.
- Parajuli, R., Dalgaard, T., & Birkved, M. (2018). Can farmers mitigate environmental impacts through combined production of food, fuel and feed? A consequential life cycle assessment of integrated mixed crop–livestock system with a green bio refinery. *Science of the Total Environment*, *619–620*, 127–143.
- Paramesh, V., Chakurkar, E. B., Bhagat, T., Sreekanth, G. B., Kumar, H. B. C., Rajkumar, S., Gokuldas, P. P., Mahajan, G. R., Manohara, K. K., & Ravisankar, N. (2021b). Impact of integrated farming system on residue recycling, nutrient budgeting and soil health. *Indian Journal of Agricultural Sciences*, *91*(1), 44–48.
- Paramesh, V., Ravisankar, N., Behera, U., Arunachalam, V., Kumar, P., Solomon Rajkumar, R., DharMisra, S., Mohan Kumar, R., Prusty, A. K., Jacob, D., & Panwar, A. S. (2022). Integrated farming system approaches to achieve food and nutritional security for enhancing profitability, employment, and climate resilience in India. *Food and Energy Security*, *11*(2), 321.
- Paramesh, V., Ravisankar, N., Behera, U., Arunachalam, V., Kumar, P., Solomon Rajkumar, R., DharMisra, S., Mohan Kumar, R., Prusty, A. K., Jacob, D., Panwar, A. S., Mayenkar, T., Reddy, V. K., & Rajkumar, S. (2021a). Integrated farming system approaches to achieve food and nutritional security for enhancing profitability, employment, and climate resilience in India. *Food and Energy Security*, *00*, e321. <https://doi.org/10.1002/fes3.321>
- Pasha, Md. L., Reddy, G. K., Sridevi, S., Govardhan, M., Ali Baba, Md., & Rani, B. (2020). Energy use efficiency and greenhouse gas emissions from integrated crop–livestock systems in semi-arid ecosystem of Deccan Plateau in Southern India. *Journal of Experimental Biology and Agricultural Sciences*, *8*(2), 98–110.
- Purnomo, S. H., Sari, A. I., Emawati, S., & Rahayu, E. T. (2021). Factors influencing the adoption of integrated crop–livestock to support land conservation of organic agriculture in Mojosoongo area, Karanganyar, Indonesia. *Earth and Environmental Science*, *724*(1), 12049. <https://doi.org/10.1088/1755-1315/724/1/012049>
- Rahman, F. H., & Sarkar, S. (2012). Efficient resource utilization through integrated farming system approach in the farmers' field at Burdwan district of West Bengal. In *Extended summaries Vol 3: 3rd international agronomy congress*, New Delhi, 997–998.
- Rana, S. S. (2015). Recent advances in integrated farming systems. Department of agronomy, college of agriculture, CSK Himachal Pradesh Krishi Vishwavidyalaya, Palampur, 204 pages. Available at: <http://www.hillagric.ac.in/edu/coa/agronomy/lect/agron-607/607-RecentAdvances-in-IntegratedFarmingSystems.pdf>.
- Ray, S. K., Chatterjee, D., Rajkhowa, D. J., Baishya, S. K., Hazarika, S., & Paul, S. (2020). Effects of integrated farming system and rainwater harvesting on livelihood improvement in north-Eastern region of India compared to traditional shifting cultivation: Evidence from an action research. *Agroforestry Systems*, *94*(2), 451–464.
- Reddy, G. K., Govardhan, M., Kumari, Ch. P., Pasha, Md. L., Baba, Md. A., & Rani, B. (2020). Integrated farming system a promising farmer and eco friendly approach for doubling the farm income in India—A review. *International Journal of Current Microbiology and Applied Sciences*, *9*(1), 2243–2252.
- Sahoo, H. K., Phonglosa, A., & Behera, B. (2020). Resource recycling for farm productivity and profitability in integrated farming system under rainfed situation in Odisha, India. *Current Journal of Applied Science and Technology*, *39*(40), 44–50.
- Salton, J. C., Mercante, F. M., Tomazi, M., Zanatta, J. A., Concenço, G., Silva, W. M., & Retore, M. (2014). Integrated crop–livestock system in tropical Brazil: Towards a sustainable production system. *Agriculture, Ecosystems & Environment*, *190*, 70–79.
- Shyam, C. S., Shekhawat, K., Rathore, S. S., Babu, S., Singh, R. K., Upadhyay, P. K., Dass, A., Fatima, A., Kumar, S., Sanketh, G. D., & Singh, V. K. (2023). Development of integrated farming system

- model—A step towards achieving biodiverse, resilient and productive green economy in agriculture for small holdings in India. *Agronomy*, 13(4), 955.
- Siddeswaran, K., Sangetha, S.P., & Shanmugam, P.M. (2012). Integrated farming system for the small irrigated upland farmers of Tamil Nadu. In: *Proceedings of 3rd International Agronomy Congress*. ICAR, New Delhi; 2012.
- Singh, R.P., Das, S.K., BhaskaraRao, U.M., & Reddy, M.N. (1990). *CRIDA report*, CRIDA, Hyderabad, India. 106.
- Singh, H., Meena, G. L., Sharma, L., Kumar, J. M., Bhushan, B., & Manju. (2018). Resource use efficiency in integrated farming systems of Banswara district of Rajasthan. *Journal of Animal Research*, 8(4), 01–06.
- Subash, N., Dutta, D., & Ravisankar, N. (2018). IFS-GHG Estimation tool ver. 1.0. A green house gases estimation tool for integrated farming system models. *AICRP-IFS, ICAR-IIFSR*, Modipuram, Meerut, India.
- Sujatha, S., & Bhat, R. (2015). Resource use and benefits of mixed farming approach in arecanut ecosystem in India. *Agricultural Systems*, 1(141), 126–137.
- Swarnam, T. P., Velmurugan, A., Subramani, T., Ravisankar, N., Subash, N., Pawar, A. S., Perumal, P., Jaisankar, I., & Dam Roy, S. (2024). Climate smart crop–livestock integrated farming as a sustainable agricultural strategy for humid tropical islands. *International Journal of Agricultural Sustainability*, 22(1), 2298189.
- Tripathi, A., & Prasad, A. R. (2010). Agricultural development in India since independence: A study on progress, performance, and determinants. *Journal of Emerging Knowledge on Emerging Markets*, 1(1), 8.
- Twine, R. (2021). Emissions from animal agriculture—16.5% is the new minimum figure. *Sustainability*, 13, 6276. <https://doi.org/10.3390/su13116276>

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