



High value crop based integrated farming system model for peri-urban small farmers of semi-arid Bundelkhand region of India

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ABSTRACT

Integrated Farming System (IFS) has been traditionally followed by small and marginal farmers within the semi-arid Bundelkhand region of central India. However, situation specific modification should be done in the existing IFS practices for optimizing productivity, profitability, and agro-ecological advantages. The study was carried from 2014 to 2021, at Central Research Farm of ICAR-Indian Grassland and Fodder Research Institute, Jhansi, Uttar Pradesh, aimed to enhance productivity, profitability, employment generation, resource utilization through recycling and soil health. It focused on the integration of high-value crops, fruits, vegetables and with dairy animals, designed for peri-urban farmers in the Bundelkhand region. The developed one ha high-value crop-based IFS model yielded a diverse range of products, including food grains, fruits, vegetables, fodder, milk, farmyard manure (FYM) and compost. IFS model generated an annual net return of ₹146,529, benefit-cost ratio of 1.8 and provided 336 man-days of employment per year. This IFS model ensured a consistent, year-round income for farmers, with monthly earnings ranging from approximately ₹17,260 to ₹39,116. Further, the system effectively recycled 10.22 t of farm yard manure (FYM) and 3.65 t of farm compost, contributing to improved soil health and a 38% increase in soil organic carbon compared to initial levels. In conclusion, this research demonstrates that a high-value crop-based IFS model is a viable strategy for peri-urban farmers in the semi-arid Bundelkhand region, enabling the production of diverse commodities, enhancing profitability and employment opportunities and improving soil health.

Keywords: High value crops, Integrated farming system, Peri-urban areas, Productivity, Profitability, Resource recycling, Soil health, Vegetables

The semi-arid area of central India, especially the Bundelkhand region is agro-ecologically fragile due to climatic and soil related challenges (Rai *et al.* 2014). The region suffers from low crop productivity and profitability, high soil and water degradation, poverty and malnutrition and high risk in farming due to frequent droughts (Garg *et al.* 2020). The primary agricultural activity in this region consists of subsistence farming, characterized by mono cropping combined with keeping of livestock (Dwivedi *et al.* 2018). Majority of the farmers (more than 86%) are

small and marginal and with limited resources. Achieving livelihood security seems to be difficult under current farming situation. Integrated Farming System (IFS) is being considered as an effective approach for enhancing rural livelihood and sustaining natural resource base in Bundelkhand region (Palsaniya *et al.* 2021).

IFS offer a holistic approach by harmoniously integrating various compatible enterprises, such as food crops, vegetables, forages, fruits, livestock, fishery, poultry, apiary, and piggery. This integration has the capacity to fulfill diverse family requirements, including food, fodder, fruits, fiber, fuel, and small timber, while simultaneously delivering a wide range of ecosystem services (Palsaniya *et al.* 2023). Moreover, the much needed vertical expansion of farming in view of exploding population and shrinking farm size is achieved by incorporating suitable multiple enterprises that require minimal space and time, thereby boosting output and providing farmers with a steady income (Palsaniya *et al.* 2024). The other benefits of IFS are self-reliance, less external dependency, higher input and resource use efficiency, better recycling of residues and by-products, higher productivity and profitability, lower risk, round the

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year employment etc. (Kumar *et al.* 2012, Kumar *et al.* 2017, Palsaniya *et al.* 2022).

Scientifically designed resource based and location specific IFS models deliver better outcome. Proximity to urban markets presents peri-urban farmers with significant opportunities to capitalize on the demand for high-value produce, such as fruits and vegetables, and dairy products. The integration of high-value crops, such as fruits and vegetables, alongside dairy livestock within peri-urban farming systems holds the potential to significantly enhance profitability. This diversification strategy may also contribute to improved agro-ecological outcomes and enhance the socioeconomic well-being of farmers. Comprehensive research investigating high-value crop-based IFS within the semi-arid Bundelkhand region remains limited. This study hypothesizes that integration of high-value crops and dairy livestock in peri-urban areas can enhance productivity, profitability, resource efficiency, and soil health. Furthermore, this integrated approach facilitates the growth of regional specific research and development strategies and technological advancements tailored for peri-urban farmers. Therefore, an attempt has been made through this study using a life cycle assessment approach for comprehensive assessment of high value crop-based IFS with objectives to know its productivity and profitability, employment generation, understanding resource recycling and impact on soil health under semi-arid agro-ecology of Bundelkhand region.

MATERIALS AND METHODS

The study was carried from 2014 to 2021 at Central Research Farm of ICAR-Indian Grassland and Fodder Research Institute, Jhansi, Uttar Pradesh. The experimental site had semi-arid climate and receives 895 mm average annual rainfall. The soil was clay loam, alkaline pH (7.8), low in available N (109 kg/ha), available P (11 kg/ha) and medium in available K (233 kg/ha) and organic carbon (OC) (0.57%). High value crop based IFS model of one ha size was developed with focus on high value crops like fruit and vegetables (Table 1). Groundnut-wheat system was taken in 0.2 ha area with monsoon rains and followed by wheat during winter season under irrigated condition. Okra-vegetable pea system was grown in 0.2 ha area during April and October months respectively with the standard package of practices. Under agri-horticulture component grafted guava saplings+seasonal vegetables are grown in 0.2 ha area. Cucurbits (sponge guard, bottle guard, bitter guard, etc.) and brinjal were grown during summers and rainy season and crucifers (cauliflower, cabbage), tomato, brinjal, chilli, spinach, etc., were grown during winters in the inter space of guava crop. Round the year forage production module involving Bajra × Napier hybrid + cowpea–berseem system was taken up in 0.3 ha area. BN hybrid rooted slips were planted in paired rows with 2.5 m in between two pairs and 75 cm × 50 cm as plant to plant spacing within pair using rooted slips during onset of monsoon rains in July. Food crops like groundnut and wheat were harvested at grain

maturity stage and seeds were collected after winnowing. Vegetables were harvested fresh on proper stage, weighed and sold in the local market. Murrah buffalo (1 no.) and one Tharparkar × Jersey crossbred cow (1 no.) were taken under animal component and these animals were maintained in animal shed. As per the recommended animal feeding diet, green fodder was harvested on daily basis, chopped into pieces and fed to animals under stall feeding along with dry fodder and concentrates. Farm compost pits were dug for preparation of compost using residues, byproducts generated from IFS farm. All these crops were grown with standard package of practices described in Palsaniya *et al.* (2021).

One ha high value crop based on-station IFS model was developed at ICAR-Indian Grassland and Fodder Research Institute, Jhansi during 2014–2018 and the vegetables, agri-horticulture and milch animals based farmers in adjoining areas of Jhansi were encouraged to adopt the same farming system activities simultaneously. Few high value crop based IFS demonstrations were also conducted on farmers' field in the area and some farmers were exposed to on-station IFS model at the research farm of the institute during various capacity building programmes like field days, farmers' fairs and training programmes etc. Detailed information on the profitability of the above IFS activities were collected during 2021 through a field survey using a well-structured questionnaire. Six farmers practicing high value crops based IFS were selected from the adjoining villages of Ambabai (Jhansi district) and Majguwan (Niwari district).

The study used the life cycle assessment and process analysis (Paramesh *et al.* 2019, Palsaniya *et al.* 2021). Detailed record of activities with all the inputs used in different components IFS and yield or outputs were recorded systematically and subjected to statistical analysis described by Palsaniya *et al.* (2021). Economic analysis, soil sample collection (initial and final) and analysis of all the IFS components was done as per the procedure described in Johl and Kapur (2015) and Palsaniya *et al.* (2021). Soil chemical properties were analyzed for pH, electrical conductivity (EC), soil organic carbon (Walkley-Black method), available N (alkaline KMnO₄ method), P (Olsen method) and K (ammonium acetate extractant method) as per the procedure outlined by Jackson (1973).

Table 1 Components of the high value crop based IFS model

Particular	Area (ha)	Component (ha)	
		Summer or rainy season	Winter season
Food crops	0.2	Groundnut	Wheat
Vegetables	0.2	Okra	Pea
Guava based agri-horticulture	0.3	Guava + (Cucurbits-winter vegetables)	
Round the year forage production module	0.3	BN hybrid + (Cowpea-Berseem)	
Animals	-	1 Buffalo + 1 cow	
Total	1.0		

RESULTS AND DISCUSSION

Productivity: High value crops based Integrated Farming System (IFS) enterprises showed variation in production (Table 2). On an average, the grain yields obtained from groundnut and wheat were 334 and 961 kg, respectively. Stover yield of groundnut after harvesting pods was about 547 kg and wheat straw yield was 1292 kg. Okra and pea were grown as vegetables under vegetables based cropping system and these vegetables produced 956 kg and 875 kg respectively while the byproduct yields were 1,401 kg and 1,361 kg, respectively. Agri-horticulture component produced 305 kg guava, 1100 kg cucurbits and 1,120 kg winter vegetables. The byproduct yield of cucurbits was 1335 kg and winter vegetables were 1506 kg which were used for compost making. The annual green fodder production from perennial NB Hybrid, cowpea and berseem was 6,591 kg (8 cuts/year), 3843 kg (rainy season) and 9,468 kg (5 cuts, winter season), respectively. Total green fodder yield from the BN hybrid + cowpea – berseem round the year green fodder module was 19,902 kg. The animal component comprising buffalo and cow, received a balanced ration. This ration incorporated perennial NB Hybrid fodder, a carbohydrate-rich cereal crop, alongside protein-rich leguminous fodders, specifically cowpea during the rainy season and berseem during the winter season.

Improvement in productivity was observed across individual components and the IFS as a whole, can be attributed to the interactive effects among the system's elements. The efficient management of resource flows, coupled with internal recirculation within the IFS framework, contributed to the enhanced performance of all components. Furthermore, the utilization of by-products from one system component as inputs for another maximized resource efficiency. The internal integration of the IFS facilitates nutrient and organic matter cycling, demonstrated by the utilization of crop residues as livestock fodder and the

application of animal manure as farmyard manure (FYM) to the soil. Further, the transformation of crop residues and weeds into compost, subsequently applied to the field, contributes to enhanced system productivity and long-term sustainability

Palsaniya *et al.* (2021) showed that implementing a diversified IFS, which included food crops, agro-forestry (fruits and vegetables), forage production, animal husbandry, and integrated fish farming, yielded enhancements across multiple parameters, including productivity, profitability, energy efficiency, resource cycling, and soil health. Consistently, various studies corroborate the observed enhancements in productivity associated with IFS. Kumara *et al.* (2017) documented increased yields across a range of IFS components, including grain crops, horticultural produce, dairy production, sheep husbandry, and vermicomposting, attributing these improvements to the interactive benefits, effective resource movement recycling processes. Likewise, Behera *et al.* (2008) underscored the favourable influence of optimized resource administration within IFS on overall productivity within the Indian agricultural landscape. Further, the advantageous contributions of integrated crop-livestock-aquaculture systems to livelihoods, employment opportunities, and food and nutritional security have been reported (Kumar *et al.* 2018, Paramesh *et al.* 2019). Sneessens *et al.* (2019) found that combined crop-livestock farming systems, characterized by diminished susceptibility to external factors, exhibit positive interrelationships between crops and livestock, reduced dependence on market fluctuations, and greater adaptability

The high value crops based IFS model reported a substantial increase in total milk production, yielding 4409 litre/lactation from Murrah buffaloes and Tharparkar × Jersey crossbred cows. Murrah buffaloes and crossbred cows produce significantly more milk than local indigenous cows, which average under 1,000 litre/lactation, and native

Table 2 Yield, economics and employment generation under high value crop based IFS (mean of 4 years)

Particular	Component	Yield (kg)	Cost of production (₹)	Gross returns (₹)	Net returns (₹)	B:C ratio	Employment (man-days)
Food crops	Groundnut	334±31 (547±37)	4,393	10,612	6,220	2.4	12
	Wheat	961±47 (1292±63)	6,487	14,387	7,900	2.2	12
Vegetables	Okra	956±51 (1401±73)	7,151	26,700	19,549	3.7	21
	Pea	875±42 (1361±64)	6,281	24,500	18,219	3.9	26
Agri-horticulture (guava + vegetables)	Guava	305±38	2,064	2,875	811	1.4	11
	Cucurbits	1100±41 (1335±84)	7,999	22,875	14,876	2.6	34
	Winter vegetables	1120±71 (1506±93)	7,979	28,050	20,071	3.5	38
Round the year green fodder module	NB hybrid (GFY*)	6591±375	3,393	6,591	3,198	1.9	11
	Cowpea (GFY)	3843±137	2,629	4,803	2,174	1.8	7
	Berseem (GFY)	9468±421	7,451	11,835	4,384	1.6	18
Animals	Milk (L)	4409±259	1,32,678	1,81,806	49,128	1.4	146
Total/average	-	-	1,88,505	3,35,034	1,46,529	1.8	336

*GFY means green fodder yield. Figures in the parenthesis are by-product of the crop and the value after± is SE.

buffaloes, which yield between 1,500 and 2,000 litre/lactation. The results of this study clearly indicates the critical role of improved animal breeds, year-round supply of high-quality green fodder (grass legume mixtures), and adequate concentrate supplementation in maximizing animal productivity and farm profitability. Palsaniya *et al.* (2021) reported higher milk yield from animal component in IFS due to balanced nutrition with carbohydrates rich in perennial BN hybrid and protein rich seasonal legumes like cowpea and berseem. Animal productivity and health are significantly improved by the provision of protein-rich fodder legumes, concentrated feeds, and a constant supply of quality green fodder has been emphasized by Dwivedi *et al.* (2018) for Bundelkhand farmers and Klapwijk *et al.* (2014) for a broader context.

Profitability and employment generation: The animal component demonstrated the highest gross (₹181,806) and net (₹49,128) returns, followed by vegetables (₹51,200 and ₹37,768 respectively) and agri-horticulture (₹53,800 and ₹35,758, respectively) (Table 2). The contribution of animal component in total net returns of high value crops-based IFS was the highest (33.5%) followed by vegetable crops (25.77%), agri-horticulture (24.4%), food crops (9.6%) and round the year green fodder module (7%) (Fig. 1). The contribution of high value based crops (vegetables and agri-horticulture) was 50.1%, which is high mainly due to their high profitability potential compared to other components. The profitability of animal components can be attributed to increased milk yield from dairy animals despite higher concentrate feed expenses. This finding highlights the significant role of fruits, vegetables and dairy animals, in boosting the financial well-being of livestock keepers in IFS. The higher net returns from dairy animals were also reported by Palsaniya *et al.* (2022), Singh *et al.* (2010) in their study of the semi-arid Bundelkhand region of central India. Ray *et al.* (2020) also found that livestock component based IFS model contributed to net income up to 56.59% and inclusion of high-yielding Murrah buffalo and crossbred cattle into the IFS system could further make IFS more remunerative.

A one ha, on-station IFS model, featuring high-value

crops, food crops, vegetables, agri-horticulture, fodder, and animals, yielded a total net profit of ₹146,529, resulting in a benefit-cost ratio of 1.8. Net return from the on-farm high value crop based IFS was ₹131136/ha (Fig. 3). High value crop based IFS enhanced returns and profitability, mainly due to increased yield of components and reduced cost of cultivation associated with decreased reliance on external input sources. Moreover, these integrated components exhibit synergistic relationships, where by-products serve as inputs, reducing external dependence and enhancing productivity, profitability, and employment generation (Kumar *et al.* 2017). Previous research confirms IFS's crucial role in farmers' livelihood security under similar conditions. The net returns increased by 36 and 226% with the inclusion of goat rearing under intensive and semi-intensive rearing system, respectively in the rainfed farming system model developed at Jhansi, Uttar Pradesh (Palsaniya *et al.* 2023). Under Bundelkhand semi-arid region, Palsaniya *et al.* (2022) found that a dairy based IFS yielded 82.7%

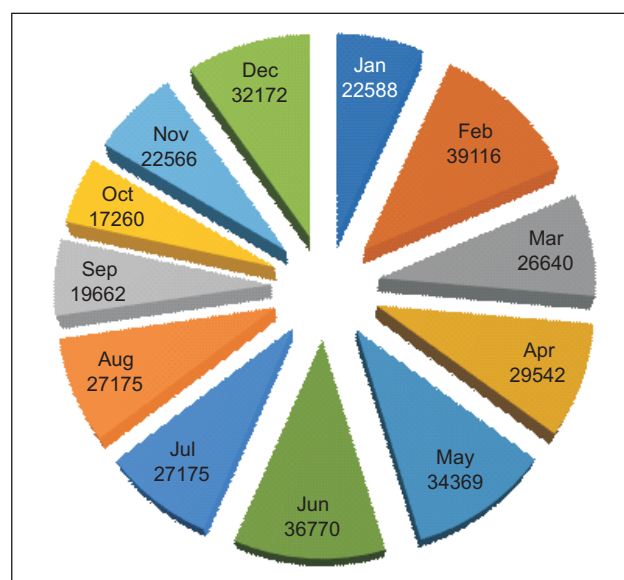


Fig. 2 Monthly distribution of gross income (₹) from high value crop based IFS.

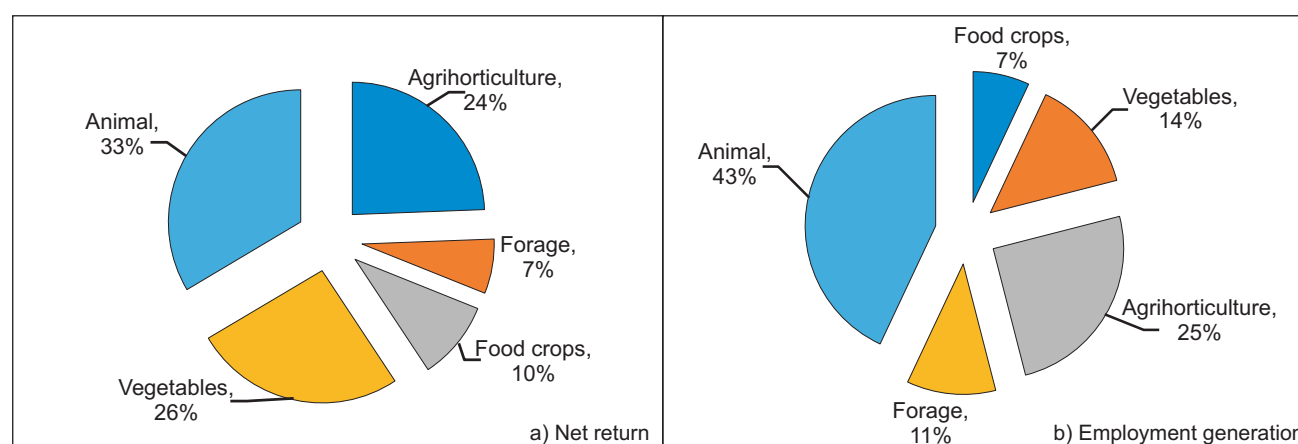


Fig. 1 Contribution of different components in net return and employment generation.

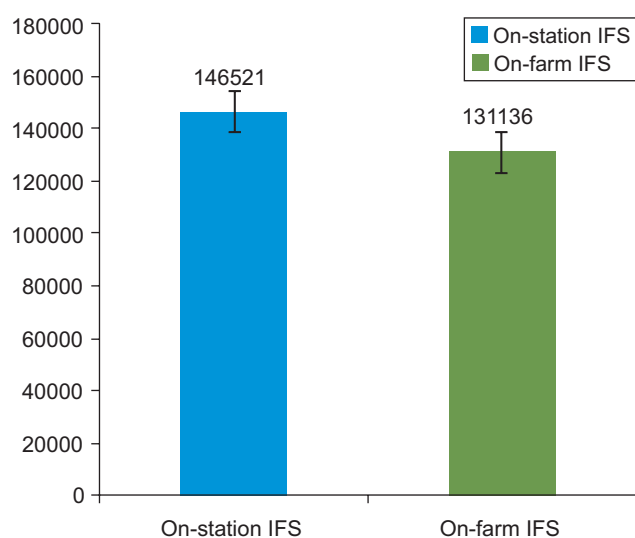


Fig. 3 Net returns (₹/ha) from on-station and on-farm high value crop based IFS.

increase in net returns, accompanied by a benefit-cost ratio of 1.52. This system also facilitated a more consistent income distribution throughout the year and generated a 251% increase in employment opportunities (418 man-days/ha/annum) compared to a double-cropping system. The animal component contributed the highest annual net returns, followed by food crops, with the animal component alone accounting for 56.2% of the total net returns in the rainfed IFS model (Palsaniya *et al.* 2024). Similarly, Singh *et al.* (2010) documented that a sesame-lentil-mustard-Murrah buffalo IFS in the semi-arid Bundelkhand region of central India resulted in the highest net profit (₹65,819/ha). Furthermore, Dwivedi *et al.* (2018) conducted an on-farm investigation in the semi-arid Bundelkhand area, revealed that IFS interventions, including improved cultivars with enhanced agronomic practices, year-round green fodder provision, fruit and vegetable cultivation, and the implementation of advanced farm machinery for labour reduction, significantly improved productivity, profitability, and farmer livelihoods.

High value crops based IFS model created 336 man-days per annum, significantly contributing to year round employment of farm family. Animal component (Murrah buffalo + cross bred cow), vegetables, agri-horticulture, fodder crops and food crops (wheat and groundnut) require more man-days in IFS. The diverse and multiple enterprises within IFS necessitate continuous labour engagement, leading to increased employment opportunities. The animal component alone provided 146 man days out of total 336 man-days/year which provided employment generation of 43%. Agri-horticulture component, vegetable cultivation and fodder crops generated 83, 47, 36 man-days/ha/year over the groundnut-wheat system (24 man-days/ha/year) (Fig. 1).

A one ha IFS design, beyond yielding a diverse range of products (grains, fruits, vegetables, fodder, milk, fish, etc.), significantly enhanced net returns and generated 293 person-days/year of employment, contrasting with the lower

net income and 119 man-days produced by a groundnut-wheat cropping system (Palsaniya *et al.* 2021). Previous research conducted within the semi-arid Bundelkhand region of India has consistently demonstrated the capacity of IFS to provide sustained employment opportunities (Singh *et al.* 2010, Dwivedi *et al.* 2018). Notably, a one ha IFS model, incorporating diverse enterprises, implemented in Jorhat, Kalyani, Pantnagar, and S K Nagar, yielded 479, 338, 409, and 297 man-days/ha/year, respectively (Panwar *et al.* 2018). The issue of rural migration from the Bundelkhand region could be mitigated through a high-value crop-focused IFS strategy, owing to its substantial employment generation potential. Within a high-value crop-based IFS, the inclusion of multiple enterprises, notably dairy, vegetables, food crops, and fruit and forage production, secured a consistent annual income for farm families (Fig. 2). IFS components provide a consistent monthly income to the farmer to meet out the house hold costs and engaged in his own farm throughout the year. In contrast, if a farmer cultivates groundnut-wheat system alone, he will get income only during April and November months. However, a farmer can get approximately ₹17,000 – ₹39,000 every month by adopting the high value crops based IFS model (Fig. 2). In this high value crops based IFS, multiple and diverse enterprises are carefully designed in such a manner that farmer get regular income flow throughout the year. Milk, seasonal vegetables and agri-horticulture were the three major components that helped farmer in getting daily income. In another study conducted at IIFSR, Modipuram by Kaur *et al.* 2021 reported the increase in income ranging from 84.8–103.2% by following different type of interventions consisting of improved crop cultivation practices, diversified crops, improved livestock rearing practices, waste recycling with inclusion of poultry. One ha IFS model involving crops, dairy, fishery, duckery, biogas plant, fruit trees and agro-forestry at IARI, New Delhi, yielded net returns of ₹3,78,784/ha/year with an employment generation of 628 man-days (Singh *et al.* 2020).

Panwar *et al.* (2018) demonstrated a one ha IFS model for south Bihar, India, which includes diversified cropping systems (0.78 ha), horticulture (0.14 ha), dairy (two cows), goat rearing (11 animals), aquaculture (0.1 ha), duck rearing (25 birds), and boundary plantations of *Leucaena leucocephala* (225 plants) and *Moringa pterigosperma* (50 plants). This IFS generated a consistent year-round income, ranging from ₹13,160–₹51,950/month. Their findings also indicated a relatively even distribution of monthly income across various IFS models implemented in Jorhat, Kalyani, Pantnagar and SK Nagar, India. Furthermore, inclusion of perennial components such as guava, Bajra-Napier hybrid, and livestock provides secured income and less prone to weather abnormalities, mitigating risk compared to annual food crops.

Resource recycling and soil health: This study demonstrated that recycling of on farm resources, residues, by products and wastes among soil-crop-animal continuum in the high value crops based IFS which improved soil health and advanced the production system sustainability. The IFS

Table 3 Changes in soil chemical properties (0–15 cm) under different components of high value crop based IFS in 5 years

IFS components	pH		EC (dS/m)		OC (g/kg)		Available N (kg/ha)		Available P (kg/ha)		Available K (kg/ha)	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Groundnut-wheat block	7.6	7.4	0.35	0.31	6.0	8.3	109	133	12	17	281	298
Okra-pea block	7.8	7.5	0.30	0.22	6.2	7.0	109	152	11	15	225	248
NBH + Cowpea-berseem block	8.1	7.9	0.40	0.38	5.7	8.7	99	154	10	18	236	269
Guava + vegetables block	7.8	7.3	0.38	0.34	5.9	8.4	107	124	13	15	267	290

approach resulted in positive changes in soil pH, EC, organic carbon, available N, P and K compared to initial values, attributed to enhanced resource recycling and selection of appropriate cropping systems (Table 3 and Supplementary Fig. 1). Slight change in soil pH and EC values were observed towards normality in all the components of the high value crops based IFS, but significant improvement in Soil Organic Carbon (SOC) content was observed in all the components. Notably, SOC significantly increased, with the highest gains observed in fodder crop systems (Napier Bajra Hybrid [NBH] + cowpea-berseem), followed by agri-horticulture (guava + vegetables), food crops, and vegetable systems, exhibiting respective increases of 53%, 42%, 38%, and 13% compared to initial levels. Similarly, available nitrogen (N) and phosphorus (P) showed substantial improvements, with the fodder crop system demonstrating the greatest increases (56% and 80%, respectively), followed by okra-pea (39% and 36%) and groundnut-wheat (22% and 42%). While available potassium (K) also increased, the magnitude of change was comparatively modest (6–14%) across all components. The enhanced soil health, particularly in the NBH + cowpea-berseem plots, can be attributed to the inclusion of legume-based crop rotations and subsequent biological nitrogen fixation. The observed improvements in available N, P, and K within the guava + vegetable system are likely due to continuous vegetable cultivation alongside the fruit crop. Furthermore, the substantial increase in SOC in this system is attributed to the application of farmyard manure (FYM) and compost derived from on-farm wastes

Palsaniya *et al.* (2022) reported that SOC content and available N was increased by 19% and 17% respectively over its initial values in the dairy-based IFS, further the SOC and available N increase was more (as high as 36%) in perennial-and legume-based forage block of IFS [BN hybrid + (cowpea or berseem)]. Similarly under rainfed IFS model, SOC content, available N, P and K were increased over initial values and the extent of increase was 39%, 24.5%, 22% and 17% respectively. *Leucaena* + TSH + *Stylosanthes* based silvipasture system recorded highest SOC (46%) followed by Indian jujube + TSH + (Sesame-chickpea) based agri-hortipasture (Palsaniya *et al.* 2024).

Resource flow analysis revealed that 10.22 t of farmyard manure (derived from animals) and 3.65 t of farm compost

(derived from crop residues and weeds) were recycled into the soil, which leads to improved soil health (Supplementary Fig. 1). Vegetable and weeds residues were recycled in the system through composting. FYM and compost together added nearly 69.4 Kg N, 25.9 kg P and 69.4 kg K/ha/year to the soil in the IFS. Out of the above amount, nearly 1/3rd of N and 2/3rd of P and K remain available to the crops in the first year of application and the rest of the nutrient is available in the subsequent years. In this resource flow 19.9 t of green fodder and 1.84 t of dry fodder were generated for feeding the animals. Palsaniya *et al.* (2022) reported that well integrated dairy-based IFS were self-reliant, created synergies on a farm and recycled resources and by-products efficiently across the components than double cropping. Under rainfed IFS model developed at Bundelkhand region, efficient resource use (FYM, farm compost from cow dung, goat manure, weeds and crop residues) and by product recycling was done in soil-plant-animal continuum which helped in improving the soil fertility (Palsaniya *et al.* 2024).

In semiarid regions, where soil responses to management interventions are typically slow process, integrated crop-livestock systems have demonstrated substantial long-term impacts on soil health (Ryschawy *et al.* 2017). For instance, an IFS incorporating crops, fish, ducks, and goats has been shown to augment soil nutrient pools, notably nitrogen (N), phosphorus (P), and potassium (K), through the effective recycling of animal and plant residues (Kumar *et al.* 2012). A comprehensive review of Indian farming systems by Behera *et al.* (2008) highlighted the resource utilization efficiency within IFS, driven by efficient resource recycling, which ultimately contributes to improved soil health, crop productivity, profitability, and sustainability. These findings are corroborated by numerous studies, underscoring the potential of crop-livestock integration as a strategic approach to simultaneously enhance livestock and crop production while safeguarding soil and ecosystem integrity through optimized resource cycling (Kumar *et al.* 2017 and Patel *et al.* 2019).

Soil organic stock and carbon sequestration rate: High value crop based IFS demonstrated 38% increase in soil organic carbon stock (SOC) over its initial value with an annual carbon sequestration rate of 1.54 Mg/ha/year (Supplementary Fig. 2). After five years of study, the SOC

stock increased by 25% (6 Mg/ha) from its initial value with an annual carbon sequestration rate of 1.25 Mg/ha/year under groundnut-wheat cropping system. Subsequently, fodder crops and agri-horticulture component recorded 21% increase in SOC stock with an annual carbon sequestration rate of 1.49 and 1.33 Mg/ha/year respectively. The increase in SOC stock was lowest (13% over their initial value) with carbon sequestration rate of 0.48 Mg/ha/year in vegetable block compared to all the components.

Studies have demonstrated the positive impact of smallholder rainfed IFS on carbon sequestration. Palsaniya *et al.* (2024) observed that these systems exhibited a 31.5% increase in carbon stock, with carbon sequestration rate of 1.36 Mg/ha/year. Notably, silvipastoral block, comprising *Leucaena*, TSH, and *Stylosanthes*, displayed the highest carbon accumulation followed by agri-hortipastoral systems, while sorghum-oat fodder systems showed the lowest. In a related study, Palsaniya *et al.* (2022) reported increases in SOC stock of 32%, 14%, and 10% in forage (BN hybrid + cowpea-berseem), agri-horticultural (guava + groundnut-wheat), and food crop (sorghum-wheat) systems, respectively, compared to initial levels. Furthermore, a decade-long investigation into IFS models revealed that fodder systems shown more Total Organic Carbon (TOC) and carbon stock accumulation. Rao *et al.* (2024) found that surface soil (0–15 cm) in 0.4 ha and 0.8 ha fodder system models exhibited 17% and 13% higher TOC and carbon stock, respectively. Consistent with these findings, Negi *et al.* (2018) and Manjunath *et al.* (2017) emphasizes that sustainable agriculture can be fostered through the implementation of IFS, which facilitate efficient resource recycling, enhance soil fertility, and promote carbon sequestration.

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REFERENCES

- Behera U K, Yates C M, Kebreab E and France J. 2008. Farming systems methodology for efficient resource management at the farm level: A review from an Indian perspective. *The Journal of Agricultural Science* **146**: 493–505.
- Dwivedi R N, Tripathi S N, Tripathi S B, Singh K A, Agrawal R K, Sahay C S, Sadhana P, Dwivedi P N, Kumar S, Singh J P, Kushawaha B P, Kumar S, Palsaniya D R, Stayapriya, Narasimhulu B and Kumar A. 2018. Enhancing productivity and livelihood of Bundelkhand farmers through crop livestock based interventions. *Current Advances in Agricultural Sciences* **10**: 84–88.
- Garg K K, Singh R, Anantha K H, Singh A K, Venkataradha A, Barron J, Dev I, Tewari R K, Wani S P, Dhyani S K and Dixit S. 2020. Building climate resilience in degraded agricultural landscapes through water management: A case study of Bundelkhand region, Central India. *Journal of Hydrology* **591**: 125592.
- Jackson M L. 1973. *Soil Chemical Analysis*. Prentice Hall of India, New Delhi.
- Johl S S and Kapoor T R. 2015. *Fundamentals of Farm Business Management*. Kalyani Publishers, New Delhi, India.
- Kaur J, Prusty A K, Ravisankar N, Panwar A S, Shamim M, Walia S S, Chatterjee S, Pasha M L, Babu S, Jat M L and Lopez-Ridaura S. 2021. Farm typology for planning targeted farming systems interventions for smallholders in Indo-Gangetic Plains of India. *Scientific Reports* **11**(1): 20978.
- Klapwijk C J, Bucagu C, van-Wijk M T, Udo H M J, Vanlauwe B, Munyanziza E and Giller K E. 2014. The 'one cow per poor family programme: Current and potential fodder availability within smallholder farming systems in south-west Rwanda. *Agricultural Systems* **131**: 11–22.
- Kumar S, Bhatt B P, Dey A, Shivani S, Kumar U, Idris M D, Mishra J S and Kumar S. 2018. Integrated farming system in India: Current status, scope and future prospects in changing agricultural scenario. *The Indian Journal of Agricultural Sciences* **88**: 13–27.
- Kumar S, Palsaniya D R, Kumar T K, Dixit A K, Das M M and Ghosh P K. 2017. *Farming systems: Issues and strategies*. SSPH Publisher, New Delhi.
- Kumar S, Singh S S, Meena M K and Dey A. 2012. Resource recycling and their management under integrated farming system for lowlands of Bihar. *The Indian Journal of Agricultural Sciences* **82**: 504–10.
- Kumara O, Sannathimmappa H G, Basavarajappa D N, Danaraddi V S, Pasha A and Rajani S R. 2017. Integrated farming system: An approach towards livelihood security, resource conservation and sustainable production for small and marginal farmers. *International Journal of Plant and Soil Science* **15**(3): 1–9.
- Manjunath B L, Paramesh V, Mahajan G R, Das B, Reddy K V, Chakurkar E B and Singh N. 2017. Sustainability through resource recycling, soil fertility and carbon sequestration from integrated farming systems in west coast India. *The Bioscan* **12**: 1–6.
- Negi V S, Maikhuri R K, Chandra A, Maletha A and Dhyani P P. 2018. Assessing sustainability of farming systems in mountain agroecosystems of Western Himalaya, India. *Agroecology and Sustainable Food Systems* **42**: 751–76.
- Palsaniya D R, Kumar S, Das M M, Kumar T K, Kumar S, Chaudhary M, Chand K, Rai S K, Ahmed A, Sahay C S and Choudhary M. 2021. Integrated multi-enterprise agricultural system for sustaining livelihood, energy use and resource recycling: A case study from semi-arid tropics of central India. *Agroforestry Systems* **95**: 1619–34.
- Palsaniya D R, Kumar S, Das M M, Kumar T K, Chaudhary M, Chand K, Rai S K, Ahmed A, Kumar S and Sahay C S. 2022. Ecosystem services from a smallholder dairy based integrated farming system vis-a-vis double cropping. *Agroecology and Sustainable Food Systems* **46**(10): 1456–81.
- Palsaniya D R, Kumar S, Das M M, Rai S K, Kumar T K, Kumar S, Chaudhary M, Chand K, Ahmed A, Sahay C S and Kumar P. 2023. Rain water harvesting, agroforestry and goat based intensification for livelihood resilience in drought prone rainfed smallholder farming system: A case for semi-arid tropics. *Agroforestry Systems* **19**: 1405–19.
- Palsaniya D R, Kumar S, Das M M, Kumar T K, Chaudhary M, Chand K, Rai S K, Ahmed A, Kumar S and Sahay C S. 2024. Ecosystem services from rain water harvesting, agroforestry and livestock based smallholder rainfed integrated farming system. *Agroforestry Systems* **98**: 2617–32.
- Panwar A S, Ravisankar N, Shamim M and 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.
- Paramesh V, Parajuli R, Chakurkar E B, Sreekanth G B, Kumar H C, Gokuldas P P, Mahajan G R, Manohara K K, Viswanatha R K and Ravisankar N. 2019. Sustainability, energy budgeting, and life cycle assessment of crop-dairy-fish-poultry mixed farming system for coastal lowlands under humid tropic condition of India. *Energy* **188**: 116101.
- Patel A M, Patel K M and Patel P K. 2019. Sustainability of farm and farmers through integrated farming system approach. *Indian Journal of Agronomy* **64**: 320–23.
- Rao K K, Samal S K, Kumar S, Singh N R, Kumar R, Mondal S, Kumar S, Mishra J S, Bhatt B P, Ravisankar N, Kumar S, Upadhyay P K, Jadhav S K and Choubey A K. 2024. Decade-long effects of integrated farming systems on soil aggregation and carbon dynamics in sub-tropical Eastern Indo-Gangetic plains. *Frontiers in Sustainable Food Systems* **8**: 1384082.
- Rai S K, Kumar S, Rai A K, Satyapriya and Palsaniya D R. 2014. Climate change, variability and rainfall probability for crop planning in few districts of Central India. *Atmospheric and Climate Sciences* **4**: 394–403.
- Ray S K, Chatterjee D, Rajkhowa D J, Baishya S K, Hazarika S and 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 action research. *Agroforestry Systems* **94**: 451–64.
- Ryschawy J, Liebig M A, Kronberg S L, Archer D W and Hendrickson J R. 2017. Integrated crop-livestock management effects on soil quality dynamics in a semiarid region: A typology of soil change over time. *Applied and Environmental Soil Science* **2017**: 3597416.
- Singh R A, Singh D and Khan K. 2010. Integrated farming for rural prosperity and livelihood security based on watershed technology in Bundelkhand. *Range Management and Agroforestry* **31**: 130–32.
- Sneessens I, Sauvee L, Randrianasolo-Rakotobeb H and Ingrand S. 2019. A framework to assess the economic vulnerability of farming systems: Application to mixed crop-livestock systems. *Agricultural Systems* **176**: 102658.