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Integrated multi-enterprise agricultural system for sustaining livelihood, energy use and resource recycling: a case study from semi-arid tropics of central India

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Abstract Integrated farming system (IFS) has been the way of life of agrarian people in semi-arid tropics (SAT) of India and other developing countries. However, there has been losing links between crops and livestock in the recent past due to promotion of mono- or double-crop-based intensive agricultural production systems owing to compulsions of hunger and poverty. Such farming practices resulted in issues of sustainability and economic viability due to stagnant productivity, deteriorating soil health, risk of failure of mono-cropping, absence of by-product and resource recycling, etc. Therefore, a study was planned during 2014–2018 involving multiple enterprises like food crops, agroforestry (fruits + vegetables), forage, livestock and water harvesting-cum-fish production to enhance productivity, profitability, energy efficiency, resource recycling and soil health. The IFS model of one hectare size besides producing multiple products (grains, fruit, vegetable, fodder, milk, fish, etc.) also resulted in US$ 1671/year net return with a benefit cost ratio of 1.58 and generated 293 man-days/year employment as against US$ 1287 net return and 119 man-days in groundnut–wheat

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cropping system. Energy efficiency, net energy gain and energy profitability were observed higher in groundnut–wheat cropping system. However, the share of indirect energy (71%) and renewable energy (67%) was more in IFS making it more self-reliant and sustainable. The IFS approach ensured round the year supply of income and a farmer can get approximately 265 to 597 US$ every month while he gets income only twice a year by adopting double cropping. Further, nearly 10.22 tonnes of farm yard manure and 2.5 tonnes of farm compost were recycled under IFS that improved soil health as compared to the double cropping. The study concluded that the IFS approach is capable of producing multiple products, improving productivity, profitability, employment opportunities, soil health and sustaining livelihood in vulnerable ecologies like SAT of central India and other parts of the world.

Keywords Energy budgeting · Integrated farming system · Productivity · Profitability · Resource recycling · Soil health

Introduction

Integrated farming system (IFS) approach has widely been recognized for sustainable upliftment of rural households. IFS combines multiple enterprises like crops, trees, livestock, fishery, etc. in a holistic manner and has the potential to meet the diverse needs (food, fodder, fruits, fibre, fuel, small timber) of the farm families (Gill et al. 2009). However, in the recent past, the focus was on mono- or double-cropping-based cropping systems (like rice–wheat) to meet the food requirement of poor farmers in developing countries like India. Such single enterprise-based production systems led to issues like stagnant productivity, declining profitability, deteriorating soil health and sustainability (Rahman and Sarkar 2012). Furthermore, the exploding human population and shrinking farm size have hardly left any scope for horizontal expansion of the land for food production. Vertical expansion is possible by integrating appropriate multiple farm enterprises requiring lesser space and time to ensure reasonable production and regular income to farm families (Gill et al. 2009). IFS is considered as a sustainable and economic agricultural land use practice because it minimizes the use of external inputs, increases resources and energy use efficiency, promotes recycling of residues or by-products (Bell and Moore 2012; Kumar et al. 2012), enhances productivity of land or farm, minimizes risks, optimizes farm income and provides round the year employment to farmer's (Kumar et al. 2017). More recently, the focus has also been oriented towards improvement and efficient utilization of natural resource base (Palsaniya et al. 2011, 2012a; Ray et al. 2020) and farm diversification (Palsaniya et al. 2012b). The multiple enterprises of IFS are integrated in a coherent manner where the interactions are synergistic and result in greater total effect than the sum of their individual effects (Palsaniya et al. 2017). Besides manifold benefits, IFS also restores farm biodiversity and maintains ecological balance (Hendrickson et al. 2008; Korikanthimath and Manjunath 2009; Patel et al. 2019).

Mono-cropping along with livestock rearing is the major farming practice in the semi-arid Bundelkhand region of central India (Palsaniya et al. 2010). Majority of the farmers depend on subsistence type of farming to meet assured, regular and balanced supply of foods along with some cash income for fulfilling family needs and payment of recurrent farm expenditure (Palsaniya et al. 2008). Groundnut, black gram, sesame, wheat, chickpea and mustard are the major crops in the region. Winter is the main cropping season and farmers leave their cattle free after harvesting of winter crops and allow them for open grazing-cum-rearing which restrict crop cultivation during summer and rainy season (Palsaniya et al. 2009). The production system in Indian SAT, especially in Bundelkhand region, is ecologically sensitive due to various climatic and soil constraints (Rai et al. 2014). The agriculture in Bundelkhand region is characterized by low and stagnant crop productivity, declining profitability, energy shortage, higher natural resource degradation (soil and water), absolute poverty and malnutrition (Palsaniya et al. 2008, 2012c). Moreover, agriculture here is a risky occupation as erratic rainfall often leads to crop failures (Palsaniya et al. 2016). The lack of alternative employment opportunities results in higher out migration from rural areas towards big cities in search of livelihood (Palsaniya et al. 2012b). Sustainable livelihood security seems to be a challenging task under the existing farming situation. The earlier studies under similar conditions have highlighted the importance of IFS for livelihood security of farmers. Dwivedi et al. (2018) while conducting an on-farm study in semi-arid Bundelkhand region revealed that integrated farming system interventions including improved varieties with agro-techniques, round the year green fodder supply, fruits and vegetables, improved farm machinery and drudgery reducing tools, etc., enhanced productivity, profitability and livelihood of farmers. Singh et al. (2010) also reported that the maximum net income (Rupees 65,819/ha) was obtained from sesame—lentil + mustard + one 'Murrah' buffalo-based integrated farming system in the semi-arid Bundelkhand region of central India. Similarly, Senthilvel et al. (1998) reported that the integration of crop + fruit trees + goat in dry land resulted in a considerable increase in income of small and marginal farmers of semi-arid tracts of Tamil Nadu, India. Kamble et al. (2017) observed that integrated farming system recorded higher average net returns (Rupees 64,380) and benefit cost ratio (10.35) in semi-arid parts of Karnataka, India. They reported higher profitability and productivity with lesser cost of cultivation under integrated farming system as compared to farmers' practice. Kochewad et al. (2017) while reviewing diverse integrated farming systems throughout India concluded that IFS diversifies farm production, increases income, improves nutritional security and promotes nutrient recycling. Socio-economic, soil health and environmental benefits of IFS approach has also been reported in similar agro-climatic conditions of Africa (Amejo et al. 2019), Australia (Bell and Moore 2012), Western Europe and South America (Peyraud et al. 2014) and other parts of Asia (Thelma 2002). Moreover, the IFS approach is reported to be more relevant and useful for developing countries (Wilkins 2008; FAO 2010; Tarawali et al. 2011).

Despite the above facts, the weak and/or losing links between livestock and land use systems is a serious concern. The proper resource recycling part is largely missing in the existing farming systems of semi-arid central India. Generally, a system approach also remains absent in such regional integrated farming systems. Detailed studies are meagre involving site-specific and resource-based multi-enterprise IFS having rain water harvesting-cum-fish pond, crops, vegetables, forages, agroforestry, etc., with proper provisions of by-product recycling in the region. The existing yield gaps and associated risk can be minimized through sustainable intensification, diversification and adoption of climate-resilient farming system. We hypothesize that farm functioning features in terms of multi-enterprise integration have positive impact in the agro-ecological performance of the system and rising socio-economic condition of the farm family. More specifically, our hypothesis is that the productivity, profitability and resource use efficiency of existing farming systems can be further enhanced through integration of high yielding crops and varieties, livestock, ensuring round the year green fodder supply to animals, rain water harvesting-cum-fish pond, perennial components like fruits and seasonal vegetables and ensuring better resource recycling and synergies among the components. Such increased integration among different farm enterprises can also create opportunities for region-specific research and development strategies and technological alternatives for farmers. The broader objectives of the present investigation were to understand the spatial dynamics and socio-economic characteristics of IFS and a framework for agricultural intensification and diversification in semi-arid agro-ecology. In the present study, an attempt has been made using a life cycle assessment approach (detailed material flow analysis) for comprehensive assessment of multi-enterprise IFS model for knowing its productivity and profitability, assess energy budgeting and understanding the resource recycling and soil health under crop–tree–livestock–fish integration. The study can provide scientific evidence for promoting crop–tree–livestock–fish integrated farming system under semi-arid situations, and making it a feasible choice for reducing external dependency for energy and inputs, sustaining production, ensuring family nutrition, maintaining soil health through better resource recycling as well as for increasing economic profits.

Materials and methods

Study site

The present study was conducted during 2014 to 2018 at Central Research Farm of ICAR-Indian Grassland and Fodder Research Institute, Jhansi, Uttar Pradesh, India. The study site was located in the SAT of central India at 25°27′ N latitude, 78°35′ E longitude and

271 m altitude (Fig. 1). The climate of the study site is semi-arid having 895.8 ± 241.2 mm mean annual rainfall with 28.7% coefficient of variation. The rainfall distribution pattern is uneven, and approximately 97% of the rain is received in around 40–48 days during the monsoon months (June to September). The average annual temperature in this region is 25 °C. In summer, mean temperature remains around 30 °C and can rise up to 47 °C during May and June**.** Soil of the site was clayey loam, alkaline in reaction (pH 7.9), low in available N (114 kg/ha) and P (11 kg/ha), medium in available K (192 kg/ha) and organic carbon (0.6%) and had 0.27 dS/m electrical conductivity.

Integrated farming system

An integrated farming system model of one hectare size was developed by integrating different enterprises. The seasonal composition along with the area of different components is shown in Supplementary Table 1.

Food crops

The food crop component was taken on 0.55 ha area and consisted of sorghum–mustard (0.25 ha) and groundnut–wheat (0.3 ha) cropping systems. The rainy season crops (groundnut and sorghum) were sown after onset of rainfall during the first fortnight of July and maintained under limited irrigation while mustard and wheat (winter season crops) were sown during second fortnight of October and first fortnight of November, respectively, and maintained under irrigated condition. The component crops were grown with the recommended package of agronomic practices. The sun-dried harvests were threshed, winnowed and finally weighed after 15–20 days of harvesting.

Round the year green fodder module

Bajra (*Pennisetum glaucum*) × napier (*Pennisetum purpureum*) hybrid + cowpea (*Vigna unguiculata*)—berseem (*Trifolium alexandrinum*)-based round the year green fodder production system was taken on 0.2 ha area. Paired rows of perennial Bajra × Napier hybrid (called BN hybrid hereafter) were planted at 75 cm × 50 cm spacing using rooted slips during first week of July and a spacing of 2.5 m was kept in between two paired rows of BN hybrid for growing of seasonal leguminous fodder crops of cowpea during rainy (second week of July) and berseem during winter (third week of October) season. The fodder crops were grown with the standard package of agronomic practices. The combination of perennial grass (BN hybrid) and seasonal leguminous forages (cowpea and berseem) ensured round the year supply of quality green fodder for animals.

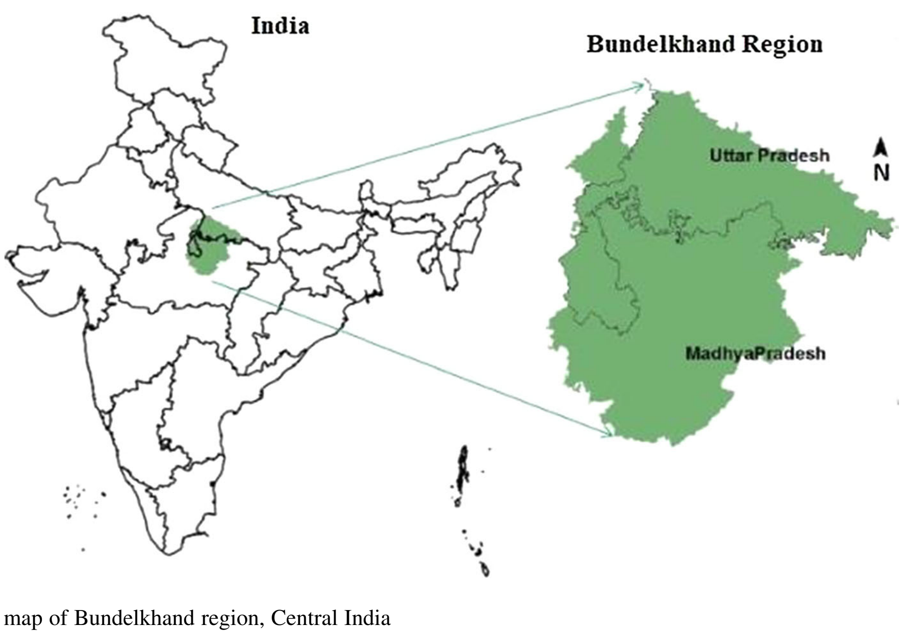

Fig. 1 Location map of Bundelkhand region, Central India

Agroforestry

The agroforestry block of 0.2 ha area was planted at 8 m × 8 m spacing and seasonal vegetables were grown in the wider spaces of two rows of guava plantation. Grafted guava sapling of cultivars *Allahabad Safeda*, *Sweta* and *Lalit* were procured from ICAR-Central Institute of Subtropical Horticulture, Lucknow and planted during August in well-prepared pits of 60 cm × 60 cm × 60 cm size. Okra and vegetable pea were sown during the second week of April and second fortnight of October, respectively, at a corresponding spacing of 45 cm × 15 cm and 45 cm × 10 cm and raised with the recommended package of practices.

Animal and fish component

The animal component comprised one *Murra* buffalo and one Tharparkar × Jersy crossbred cow and these were maintained under stall feeding in a low-cost animal shed. Daily 25–26 kg green fodder was harvested, chopped and fed to animals along with dry fodder and concentrates as per the recommended animal feeding diet. On an average, each animal produced 25 kg of fresh dung per day. A water harvesting-cum-fish pond was dug in 0.05 ha area (20 m × 25 m × 2 m) for rain water harvesting and fish production. Fingerlings of *Catla catla* and *Labeo rohita* were released in the fish pond during the second fortnight of August when sufficient rain water was collected in the pond. Cow dung was added to the fish pond before releasing fingerlings for growth of planktons and fish feed was applied at 2% of the fish body weight. Compost pits were dug for preparation of compost for better residue/by-product management and nutrient recycling.

Groundnut–wheat cropping system

Groundnut–wheat is the prominent cropping system of central Indian semi-arid tropics. Therefore, the above cropping system was grown on a separate nearby plot of 500 square metre size for making comparison with multi-enterprise IFS. The groundnut–wheat cropping system was grown with the standard package of practices and its inputs and outputs were recorded and converted into per hectare basis for comparison with the performance of IFS.

Life cycle assessment and data analysis

Life cycle assessment, input/output analysis and process analysis were used in this research (Jones 1989; Jianbo 2006; Paramesh et al. 2019). A detailed inventory was prepared and the inputs used in different components of the IFS like food, fodder and agroforestry crops, livestock, and fishery and their outputs were recorded systematically on a regular basis. The yield or output of all the components was recorded and the standard error of the mean (SEM) was calculated as per Eq. (1).

$$\mathrm{SEM} = \frac{\sigma}{n} \tag{1}$$

where σ and n are standard deviation and sample size, respectively. The SEM provides a rough estimate of the interval in which the population mean is likely to fall.

Wheat equivalent yield

The wheat equivalent yield (WEY) was calculated to compare different farming system components. WEY was calculated by converting the economic yield of groundnut, mustard, sorghum, fodder, guava, pea, okra, milk yield and fish production on the basis of their respective marketable price prevailing during the period, and expressed in tonne per unit area (Ahlawat and Sharma 1996) as shown in Eq. (2).

$$\mathrm{WEY} = \frac{\text{Yield of component crop (kg)} \times \text{Price of component crop}\left(\text{US\$kg}^{-1}\right)}{\text{Price of wheat}\left(\text{US\$kg}^{-1}\right)} \tag{2}$$

Energy analysis

The inputs were categorized as direct energy inputs (manual work, fuel and electricity), indirect energy inputs (seeds, fertilizers, manure, pesticides and water), renewable energy inputs (seeds, organic manure, water and manual work) and non-renewable energy inputs (chemical fertilizer, pesticide, fuel and electricity) as described by Choudhary et al. (2017). The inputs and outputs of different enterprises of IFS were multiplied to their corresponding energy equivalents (as described by Devasenapathy et al. 2009; Pimentel and Burgess 1980; Komleh et al. 2011; Wells, 2001; Paramesh et al. 2019) to compute energy input–output relationship. Further, the energy use indices like energy use efficiency, net energy gain and energy profitability are calculated as per Eqs. (3, 4 and 5) (Devasenapathy et al. 2009):

$$\text{Energy use efficiency} = \frac{\text{Energy output}(\text{MJ})}{\text{Energy input}(\text{MJ})} \quad (3)$$

$$\text{Net energy gain}(\text{MJ}) = \text{Energy output}(\text{MJ}) - \text{Energy input}(\text{MJ}) \quad (4)$$

$$\text{Energy profitability} = \frac{\text{Net energy gain}(\text{MJ})}{\text{Total energy input}(\text{MJ})} \quad (5)$$

where MJ is Mega Joule.

Economic analysis

The input output inventory of all the components of the integrated farming system and groundnut–wheat cropping system was maintained. The cost of cultivation and gross return were computed as per prevailing market rates in case of inputs (fertilizers, farmyard manure, insecticides, herbicides, seeds, planting material, feed, concentrates, machinery, etc.) and outputs (vegetables, fruits, fish and milk) and support price for grain crops. Minimum wage rate was used while calculating labour cost. The minimum wage rate is the government fixed wage rate in India and no labour should receive wages below it. The cost component in IFS included two types of costs—fixed cost and variable cost. The cost of inputs like seeds, fertilizers, herbicides, pesticides, ploughing, irrigation, labour charges, etc. include variable cost. The one-time initial investment especially in perennial components, construction of animal shed, purchase of animals, digging of farm pond, establishment of guava, etc. forms the fixed cost. Fixed cost was incurred during the first year of the IFS project. The fixed cost incurred during the first year needs to be spread through the subsequent years. Therefore, the fixed cost in subsequent years was calculated by adding the interest on initial investment (@7%/annum) and depreciation. This fixed cost was added to the variable cost every year to calculate total yearly cost. The depreciation amount was calculated as per Eq. (6) using formula described by Johl and Kapur (2015).

$$\text{Depreciation} = \frac{\text{Purchase value} - \text{Junk value}}{\text{Length of useful life}} \quad (6)$$

Finally, the net return (gross return–total cost) and benefit cost ratio (BCR) were calculated. The BCR was calculated on gross return basis using formula in Eq. (7).

$$\text{BCR} = \frac{\text{Gross return}}{\text{Total cost}} \quad (7)$$

Soil parameters

The soil samples were taken before the start of the experiment in the year 2014 and after 4 years on completion of the study in 2018 from different places in the field. The 1 ha IFS field was divided into four blocks (groundnut–wheat, sorghum–mustard, forage and agroforestry block) as per its components. A total of five samples were collected from each component block of IFS from the 0–15 cm and 15–30 cm layer using soil auger to make their respective composite samples. After that, the soil samples were air-dried and ground to pass through a 2-mm sieve before analysis. Chemical analysis of soil samples was done for pH (1:2.5 soil: water suspension), electrical conductivity (EC), soil organic carbon (Walkley–Black method), available N (alkaline $KMnO_4$ method), *P* (Olsen method) and *K* (ammonium acetate extractant method) as described by Jackson (1973). The soil properties under 15–30 cm did not show much variation. Therefore, the soil properties under surface plough sole layer (0–15 cm) are described under the results and discussion.

Results and discussion

Components and system productivity

The various components of the integrated farming system performed differently in terms of production and wheat equivalent yield (Table 1). Groundnut–wheat and sorghum–mustard were two food-based cropping systems in the study. The grain yield obtained from wheat, mustard, groundnut and sorghum was 1339, 357, 320 and 288 kg, respectively. Wheat recorded the highest wheat equivalent yield (1339 kg) followed by mustard (830 kg), groundnut (824) and the lowest in sorghum (Table 1). On an average, the agroforestry components produced

Table 1 Yield, wheat equivalent yield (WEY), economics and employment under IFS and groundnut–wheat cropping system (mean of 4 years)

	Particulars	Component	Yield (kg)	WEY (kg)	Cost of production (US$)	Gross returns (US$)	Net returns (US$)	B:C ratio	Employment (man-days)
IFS	Food crops	Groundnut	320 ± 28 (442 ± 31)	824	118	230	112	1.9	18
		Wheat	1339 ± 23 (2134 ± 83)	1339	151	460	310	3.1	18
		Sorghum	288 ± 11 (874 ± 31)	280	69	122	53	1.8	12
		Mustard	357 ± 12 (469 ± 23)	830	88	228	140	2.6	11
	Agroforestry (guava + vegetables)	Guava	218 ± 48	247	24	48	24	2.0	11
		Okra	348 ± 41	484	90	122	31	1.3	23
		Pea	267 ± 61	392	69	114	45	1.7	26
	Round the year green fodder module	NB hybrid (green biomass)	6482 ± 580	350	33	92	60	2.8	7
		Cowpea (green biomass)	3862 ± 146	268	30	67	37	2.2	5
		Berseem (green biomass)	8935 ± 567	621	74	154	80	2.1	12
	Fish	–	87 ± 3	539	109	132	23	1.2	5
	Animals	Milk (litres)	4409 ± 259	10,896	2041	2797	756	1.4	146
	Total	–		–	2895	4566	1671	1.58	293
Groundnut–wheat	Cropping system	Groundnut	1067 ± 56 (1472 ± 88)	–	839	2126	1287	2.55	119
		Wheat	4463 ± 76 (7113 ± 105)						

Figures in the parenthesis are by-product of the crop and the value after ± is SE

The currency mean exchange value: 1 US $ = 65 Indian Rupee (₹)

348 kg okra, 267 kg pea pods and 218 kg guava fruits. The equivalent yield in terms of wheat was the highest for okra (484 kg) followed by pea (392 kg) and guava. The total green fodder production from the BN hybrid + cowpea—berseem round the year green fodder module was 19,279 kg. The green fodder consisted of 6482 kg from perennial BN hybrid (8 cuts/year), 3862 kg from cowpea (during rainy season) and 8935 kg from berseem obtained in five cuts during winter season (Table 1). The animal got balanced ratio in terms of carbohydrate-rich cereal fodder (perennial BN hybrid) and protein-rich leguminous fodder from cowpea (rainy season) and berseem (winter season). The excess green fodder was preserved as silage for utilization during the lean period. Among the fodder crops, the equivalent yield in terms of wheat was the highest for berseem (621 kg) followed by BN hybrid (350 kg) and cowpea (Table 1). In IFS, the various food crops produced total 3450 kg dry fodder/year comprising wheat straw (2134 kg), sorghum stover (874 kg) and groundnut stover (442 kg). This straw/stover was fed to animals in their balanced diet.

The total milk yield of Murra buffalo and crossbred cow (Tharparkar × Jersy) in the integrated farming system model was 4409 L/lactation which is much higher than the average milk yield of indigenous cows (< 1000 L/lactation) and buffaloes (1500–2000 L/lactation). It is evident from this study that improved animal breeds, round the year supply of quality green fodder (grass legume mixture) and adequate concentrate use are essential for realizing higher animal productivity and farm profitability. The importance of protein-rich fodder legumes and concentrates in the animal diet and round the year supply of green fodder for higher productivity and health have also been highlighted for Bundelkhand farmers by Dwivedi et al. (2018) and for elsewhere farmers by Klapwijk et al. (2014). Fish farming is popular in semi-arid parts of central India, especially Bundelkhand region where rugged and undulating topography and hard underground strata result in a number of reservoirs where rain water gets stored (Palsaniya et al. 2009, 2011). Rain water harvesting and integrating fish in small and marginal farming systems in such areas may improve livelihood and family nutrition. In the present IFS study, fingerlings of *Catla catla* and *Labeo rohita* were released in the fish pond (0.05 ha size) during the second fortnight of August with sufficient rain water harvesting. The pond was dug in a low-lying area where water level usually remains maintained up to February–March once it gets filled during July when monsoon starts. On an average, 87 kg fish were harvested/year in the month of April when water level recedes. The wheat equivalent yield of animal component was the highest (10,896 kg) amongst the integrated farming system components and it remained 539 kg for fish. It is evident from the results that integration of enterprises in IFS offers an opportunity to increase system productivity. As compared to the above diversified and high production of multiple products from IFS, the groundnut–wheat cropping system could able to produce only 1067 kg pods and 1472 kg haulm yield/ha from groundnut and 4463 kg grain and 7113 kg/ha straw yield from wheat (Table 1).

The higher productivity and equivalent yield of different components and the IFS as whole as compared to groundnut–wheat cropping system could be attributed to the positive interactions and synergies among the components of IFS as compared to mono-cropping. The better resource flow and recycling among various components under IFS resulted in higher productivity. The by-product of one component under IFS was used as input under another component. Some of the examples of resource recycling under IFS are use of crop straw and/or stover from field in animal diet, animal dung as FYM in the soil, dung in fish pond, crop residues and weeds converted into compost and used in the field, etc. Such recycling and synergy is absent in mono-cropping. Kumara et al. (2017) also reported higher production under IFS due to synergistic interactions and better resource flow. They recorded 16.04 t/ha/year of rice equivalent yield from crops, 11.80 t/ha/year of rice equivalent yield from horticultural component, 1.75 t/ha/year of rice equivalent yield from dairy, 0.10 t/ha/year of rice equivalent yield from sheep unit and 1.88 t/ha/year of rice equivalent yield from vermi-compost in a farming system model. Behera et al. (2008) while reviewing farming systems of India observed that efficient resource management under IFS results in higher productivity. Positive impact of crop–animal–fish system on livelihood, employment and food and nutritional security were observed by Kumar et al. (2018) and Paramesh et al. (2019). Sneessensa et al. (2019) also concluded that less vulnerable mixed crop-livestock systems have more and favourable crop-livestock interactions, less market dependency and greater flexibilities.

Profitability and employment generation

The component-wise cost of cultivation, gross return, net return, benefit cost ratio and employment generation as well as for the whole integrated farming system and groundnut–wheat cropping system are given in Table 1. The higher monetary gain in terms of net return was recorded in animal component (US$ 756) followed by food crops (US$ 615). The contribution of animal component in total net returns of IFS was the highest (45%) followed by food crops (37%), forages (11%), agroforestry (6%) and fish (1%). The higher net return from the animal component may be attributed to higher milk yield while the more cost of production in this component occurred due to higher cost of concentrates. The higher return from the animal component highlighted the importance of animals in improving the livelihood of livestock keepers. The higher net return from animal component was also reported by Singh et al. (2010) in the semi-arid Bundelkhand region of central India. Ray et al. (2020) also observed that inclusion of livestock components in the IFS model contributed to as high as 56.59% enhancement of net income. It is evident from the study that we should include high yielding Murrah buffalo and cross-bred cattle in the IFS to make it more remunerative. The total net return from the one-hectare IFS model comprising food crops, fruit, vegetables, fodder, animals and fish was US$ 1671 with a benefit cost ratio of 1.58. While on the other hand, the groundnut–wheat cropping system was able to produce only US$ 1287/ha net return with 2.55 benefit cost ratio. The multi-enterprise IFS recorded

US$ 384 more net return which was 29.9% higher than the net return obtained in the groundnut–wheat cropping system. The higher returns and profitability under IFS could be attributed to more yield from components and lower cost of cultivation due to lesser dependence on external inputs. The enterprises in an integrated farming system interact synergistically and the by-product or output of one component is used as input in another which minimizes the external dependence and leads to higher productivity, profitability, employment generation, etc. (Palsaniya et al. 2017). Accatinoa et al. (2019) concluded that greater synergies among the components of IFS were largely responsible for enhanced income. Similarly, higher in-farm diversity may also help in increasing and stabilizing return on capital in such agro-ecosystems (Pacín and Oesterheld 2014). Singh et al. (2010) also reported that the maximum net income (Rupees 65,819/ha) was obtained from crop and 'Murrah' buffalo-based integrated farming system in the semi-arid Bundelkhand region of central India. Higher income and more secured livelihood of the semi-arid Bundelkhand farmers through crop–livestock-based interventions were also reported by Dwivedi, et al. (2018). Similar findings on consistency in income and employment generation in various farming systems were also observed by other researchers (Singh et al. 1997; Ramrao et al. 2005; Suresh and Singh 2008).

The integrated farming system model generated 293 man-days/year and showed huge potential of engaging the farm family through providing continuous employment. The groundnut–wheat cropping system was able to generate only 119 man-days/year. The diverse and multiple enterprises in IFS needs round the year man-power engagement and thus resulted in more employment generation as compared to double cropping. The animal component, vegetables and food crops like wheat and groundnut needed more man-days requirement in IFS. Other workers while working in semi-arid Bundelkhand also found IFS more consistent in employment generation (Singh et al. 1997, 2010; Dwivedi et al. 2018). Panwar et al. (2018) also reported that a one-hectare IFS model comprising diversified enterprises located at Jorhat, Kalyani, Pantnagar and SK Nagar generated 479, 338, 409 and 297 man-days/ha/year, respectively. Similarly, Ray et al. (2020) reported that integration of different components in IFS increased employment opportunities to 506 man-days/ha/year over the traditional system (72 man-days/ha/year) in northeast India. The problem of out migration from Bundelkhand region can be solved through integrated farming system approach because of its higher employment generation potential.

In IFS, the multiple enterprises, especially vegetables, fruit, fish and dairy, ensured year-round income to the farm family (Fig. 2). The farmer gets some income almost every month and is able to meet his household expenses and other farm needs in IFS while he gets income only twice during April and November in case of groundnut–wheat cropping system. A farmer can get approximately 265 to 597 US$ every month by adopting the above IFS model (Fig. 2). On the other hand, he gets income only twice, i.e., on harvest of winter crop (April) and rainy season crop (November) if he adopts groundnut–wheat cropping system. This is so because the multiple components of IFS under present investigation are set in such a manner that farmer get regular income flow throughout the year. Milk and seasonal vegetables were the two major components that helped in getting some daily income. Panwar et al. (2018) also reported that a one-hectare IFS model comprising of diversified

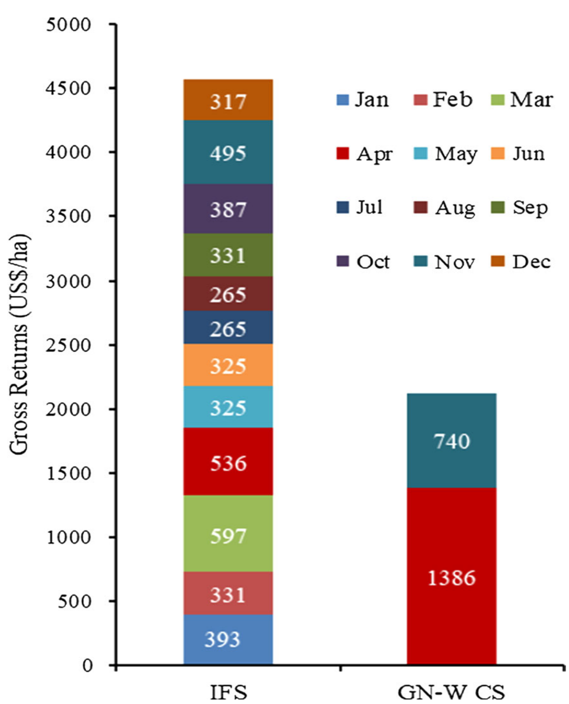

Fig. 2 Monthly income distribution in multi-enterprise IFS and groundnut–wheat cropping system (GN-W CS)

cropping systems (0.78 ha) + horticulture (0.14 ha) + dairy (2 cows) + goat (11 no's) + fish (0.1 ha) + ducks (25 no's) + boundary plantation (*Leucaena leucocephala,* 225 plants and *Moringa pterigosperma*, 50 plants) developed for the South Bihar, India ensured round the year income which ranged between Rupees 13,160 to 51,950 /month. They further reported fairly distributed monthly income from different IFS models located at Jorhat, Kalyani, Pantnagar and SK Nagar in India. Moreover, the perennial components like guava, Bajra– Napier hybrid and livestock provides risk proofing to the farmer as they are more stable and less prone to aberrant weather conditions than food crops.

Energy use pattern and budgeting

The energy input use pattern was computed for all the components of IFS as well as groundnut–wheat cropping system (Supplementary Table 2, Table 2 and 3 and Fig. 3 and 4). The total energy of 46,195 and 26,205 MJ/ha was consumed in the IFS as a whole and groundnut–wheat cropping system, respectively. Of the total energy used in the IFS, the maximum consumption was found in livestock (43%) followed by food crops (32%), agroforestry (11%), fodder crops (9%) and fish (5%) component (Fig. 3a). Livestock consumed a considerable amount of input energy (20,090), out of which 17,016 MJ consumed alone in the feed component. The higher input energy in the livestock production was mainly due to the consumption of large amounts of energy-rich feed. The input-wise energy use analysis in IFS (Fig. 4a) revealed that livestock feed consumed the bulk of the energy (37%) followed by fertilizers (13%), electricity (12%) and water (10%). Similar studies also reported higher input energy in the dairy/livestock component of integrated farming systems (Kumar et al. 2019; Paramesh et al. 2019).

Food crops recorded the highest share (39%) in total energy output and closely followed by livestock (34%) and fodder (26%) while the share of fish was less than 1% (Fig. 3b). About 9% of the total input energy was consumed in manual labour showing less farm mechanization. Deike et al. (2008) also recorded the largest shares of energy input in diesel fuel (29%) and mineral fertilizers (37%) in an integrated farming system. In the present study, in groundnut–wheat cropping system (Fig. 4b) the bulk of energy was also used in fertilizers (28%), diesel (21%) and electricity (17%). In the agroforestry component, the maximum energy was consumed in the form of electricity (1145), water (979) and manual labour (931 MJ) (Table 2). Fruit and vegetable cultivation are labour intensive as they require frequent pickings and irrigation for longer duration. This leads to higher consumption of water, electricity and labour. Similarly, out of the total 14,712 MJ energy consumption in food crops, the nitrogenous fertilizer alone consumed 3781 MJ followed by diesel (2939 MJ). Similar to the agroforestry component, electricity accounted for the highest share of the input energy in fodder crops. The share of direct

Table 2 Energy input (MJ) in different components of IFS and groundnut–wheat cropping system

Inputs	IFS					Groundnut–wheat cropping system
	Food crops	Agroforestry	Fodder crops	Fish	Livestock	
Seeds	1123	318	98	–	–	3470
Fertilizer N	3781	436	642	–	–	6363
Fertilizer P_2O_5	549	204	170	–	–	1021
FYM/compost	2160	840	795	21	–	–
Insecticide	–	55	–	–	–	–
Herbicide	127	–	–	–	–	–
Water	1561	979	734	1020	88	3675
Diesel	2939	394	265	–	–	5518
Labour	646	931	373	78	2289	1866
Electricity	1825	1145	859	1014	697	4295
Concentrate/feed	–	–	–	19	17,016	–

Table 3 Energy input–output relationship of different components of IFS and groundnut–wheat cropping system

Inputs	IFS						Groundnut–wheat cropping system
	Food crops	Agroforestry	Fodder crops	Fish	Livestock	Total	
Energy input (MJ)	14,712	5303	3937	2152	20,090	46,195	26,205
Energy output (MJ)	49,284	1583	32,108	401	42,795	126,171	199,687
Energy efficiency	3.35	0.30	8.16	0.19	2.13	2.73	7.62
Net energy gain (MJ)	34,572	−3721	28,171	−1751	22,705	79,976	173,482
Energy profitability	2.35	−0.70	7.16	−0.81	1.13	1.73	6.62
Direct energy (DE)	5411	2471	1497	1092	2986	13,457	11,679
Indirect energy (IE)	9301	2832	2440	1060	17,104	32,738	14,526
Renewable energy (RE)	5489	3068	2001	1138	19,394	31,090	9008
Non-renewable energy (NRE)	9223	2235	1936	1014	697	15,104	17,197

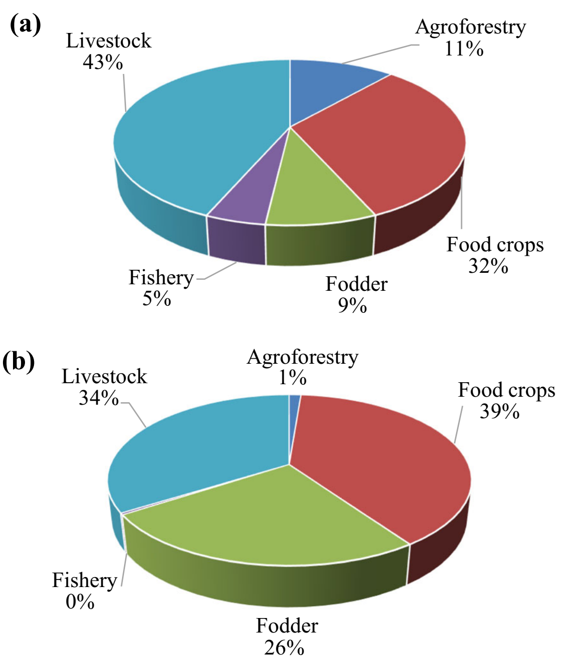

Fig. 3 Percentage share of different components of IFS to total **a** energy input and **b** energy output

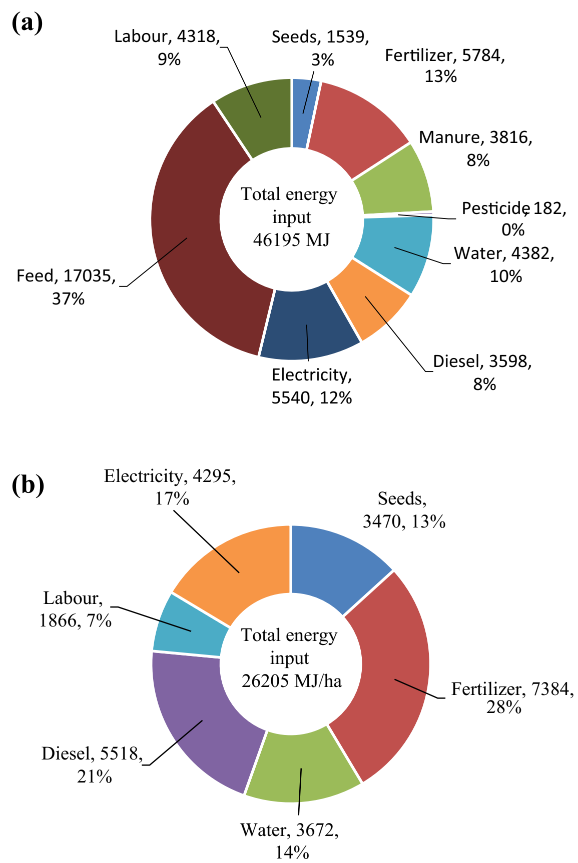

Fig. 4 Percentage share of different inputs to the total energy input of **a** IFS model and **b** groundnut–wheat cropping system

and indirect energy inputs to the total energy input of IFS was 29% and 71%, respectively, whereas renewable and non-renewable energy inputs were 67% and 23%, respectively (Table 3). Mohammadi et al. (2014) reported that specialized farms (focusing on crop production) heavily depend (75%) on non-renewable energy inputs while IFS relies largely on renewable inputs. Integrated farming systems have also been found to be the most efficient in terms of energy use as compared to conventional farms in the UK (Bailey et al. 2003).

Table 3 presents the results of the energy performance of the individual components as well as the overall IFS. The results indicated that the livestock component consumed higher energy input (20,090 MJ) and produced higher output (42,795 MJ) over other enterprises except food crops. However, the higher energy efficiency was observed with fodder crops (8.16) followed by food crops (3.35), this was mainly due to lower energy consumption as well as higher energy output in food and fodder crops. Furthermore, the net energy gain was also found higher in food and fodder crops due to large differences between energy output and input. Kumar et al. (2019) also recorded high energy use efficiency in fodder crops (8.66) followed by field crops, vegetables, fruits, mushroom, poultry and goatry. It is important to mention that fishery was the least energy-efficient agricultural production system which produced negative energy balance. The high value of energy profitability was also recorded in fodder crops (7.16) followed by food crops (2.35) while negative values were found in agroforestry (−0.70) and fishery (−0.81) components of IFS. The higher positive value is mainly due to higher net energy gain in comparison with energy input. Potential yield of guava fruit trees is generally realized after 7–10 years of planting. In the initial years of planting, marginal fruit yield was recorded which led to lower energy output. Hence, negative value was found in the agroforestry component of present studied IFS. The data presented in the study pertain to 5 years; however, the positive value of energy profitability in agroforestry may be obtained in the long run.

The energy analysis of the prominent cropping system of the region (groundnut–wheat) was also done for comparison with IFS (Table 3). It showed that total energy input in the groundnut–wheat cropping system was 57% of the IFS but output energy was 58% higher making it energy efficient. Though higher energy was consumed in IFS, the share of direct energy to the total energy was 29% in IFS as compared to 45% in groundnut–wheat cropping system. The groundnut–wheat cropping system was more reliant on direct energy for their energy requirement than IFS due to higher consumption of fertilizers and fuel. Saving of these inputs might be possible by utilizing on-farm resources like compost, FYM, etc. as in IFS. The study highlighted that the present IFS is energy efficient and largely relies on renewable energy sources. The IFS recorded energy efficiency of 2.73 which was found higher from that of a crop–livestock–poultry system (2.27) in eastern India (Kumar et al. 2019). Berton et al. (2020) also reported dairy-based farming system as food balanced, more productive, self-reliant and efficient in resource use.

Resource recycling and soil health

The present study highlighted that the farm resources, residues, by-products and wastes were properly recycled among soil–crop–animal continuum in the integrated farming system. This has improved soil properties, maintained the health of all components and imparted sustainability in the production system. The IFS approach resulted in improvement in soil PH, EC, organic carbon, available N, P and K over initial values due to better resource recycling and selection of healthy cropping systems (Table 4). On an average, the extent of increase in soil organic carbon, available N, P and K was 24, 28, 32 and 17% over initial level, respectively, in IFS. Further, the improvement in soil health was more in plots where legume-based crop rotations were followed because of biological nitrogen fixation by the legumes. On the other hand, the soil PH, EC, organic carbon, available N, P and K content were reduced in the groundnut−wheat cropping system due to the absence of resource recycling. The resource flow showed that 10.22 tonnes of farm yard manure (FYM) and 2.5 tonnes of farm compost prepared from residues and weeds were recycled in the soil which led to improvement in the soil health under IFS (Fig. 5). The non-edible mustard stover, vegetable residues (okra) and weeds were recycled in the system through composting. The FYM and compost together added nearly 52.1 kg N, 23.4 kg P and 42.1 kg K per hectare per 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. Ryschawy et al. (2017) also reported that integrated crop–livestock systems can have significant effects on soil health over time, particularly in semi-arid regions where soil responses to management occur slowly. Kumar et al. (2012) reported that crop + fish + duck + goat-based IFS added appreciable quantity of N, P and K into the system in the form of recycled animal and plant wastes. Behera et al. (2008) reviewed

Table 4 Changes in soil properties under different components of IFS and groundnut–wheat cropping system after 5 years in relation to their initial value

Production system	Sub-block	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
IFS	Food crop block	Sorghum–mustard	7.9	7.8	0.30	0.31	6.4	8.3	118.4	146.5	13.0	16.9	161.9	190.4
		Groundnut–wheat	8.0	8.4	0.27	0.22	5.9	7.5	122.4	158.4	12.6	16.1	224.7	256.5
	Forage block	NBH + Cowpea–berseem	8.3	8.8	0.39	0.38	6.3	8.2	110.6	164.3	10.2	15.7	220.2	277.8
	Agroforestry	Guava + vegetables	7.8	8.3	0.26	0.34	6.8	7.6	141.3	163.4	12.6	15.3	231.4	259.8
Groundnut – wheat cropping system			8.2	8.2	0.26	0.25	5.7	4.9	127.8	119.5	11.9	10.5	215.6	208.7

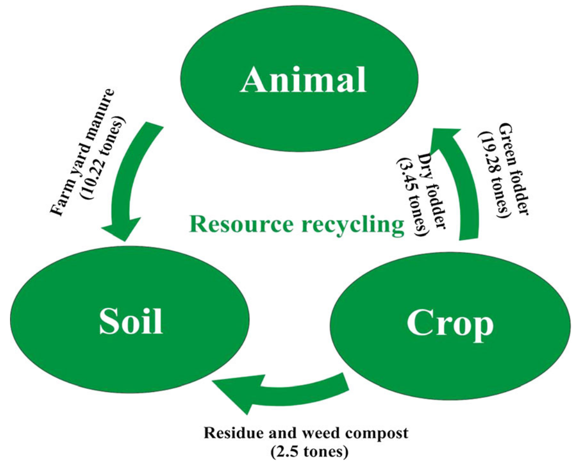

Fig. 5 Resource flow and recycling in soil–crop–animal continuum in IFS

farming systems of India and concluded that IFS approach has proper resource recycling and efficient resource use which ultimately results in better soil health, productivity, profitability and sustainability. Negi et al. (2018) and Manjunath et al. (2017) reported that sustainability in production systems can be achieved through proper resource recycling, soil fertility improvement and carbon sequestration by adopting integrated farming systems. Similar findings were also reported by the other workers and it was confirmed that the crop–livestock integrated farming system could be the key solution to enhancing the livestock and crop production and protecting the soil and ecosystems through effective recycling and use of products and resources (Liebig et al. 2012; Kumar et al. 2017; Patel et al. 2019).

Limitations and future thrust area

The integrated farming systems research is dynamic in nature and continuously evolving. Moreover, it is resource-based and situation-specific and has complex interactions amongst its components as well as the socio-economic and technological matrix of the farm family. Therefore, farmer-specific and situation-based constant efforts should be made to make it more and more productive, profitable and sustainable. The profitability and employment generation of such IFS can be further enhanced by creating suitable value chains (processing and value addition) and market linkages and inclusion of other need-based and situation-specific enterprises like mushroom, bee keeping, etc. Therefore, resource-based and farmer-specific IFS models need to be developed and popularized and may be further upgraded through inclusion of mechanization, processing and value addition and ensuring social perspective to cope with the regional and specific demands of small and marginal farmers. Despite being a highly productive, profitable and sustainable system, the adoption of IFS by the farming community is not encouraging due to fragmented approach at individual level. Therefore, constant efforts in making IFS-based clusters, providing government policy support and emphasis on widespread participatory demonstrations, etc., is needed for its up-scaling.

Conclusion

Integrated multi-enterprise farming system was found effective in enhancing productivity, profitability, energy use and soil health as compared to groundnut–wheat cropping system. The benefits were observed in terms of higher production, more income, higher employment generation, energy-saving and self-reliance, better resource recycling, improved soil health and sustainability. The selection of suitable synergistic enterprises, effective resource/by-product flow amongst various components, availability of round the year quality green fodder (cereal–legume mixture) to animals for higher milk production, regular income flow from milk, fruit and vegetables and the higher dependency on indirect and renewable energy sources highlighted that IFS can be made viable, profitable, eco-friendly, risk proof, inter-dependent and self-sustainable. Rain water harvesting and subsequent use for fish production, perennial BN hybrid-based round the year quality green fodder production system for dairy animals, and guava and vegetable-based agroforestry systems can be ideal options for semi-arid farmers of central India. The higher employment generation potential of IFS indicated that the problem of out migration from the central India, especially Bundelkhand region, can be solved to some extent by adopting this approach. The present study highlighted the significance of the crop–tree–livestock–fish integrated farming system in making the agricultural production system self-reliant and sustainable in terms of energy use. This study further revealed that the IFS approach results in efficient recycling of resources, by-products and waste materials to soil and not only improves soil health but also minimizes the external dependence for nutrients. Adoption of IFS approach by the farmers through strong extension and some government support may be the best strategy in the prevailing climate change-induced environmental stresses and ecological imbalance in the much vulnerable SAT. Further, the possibility of integrating suitable situation-specific and compatible enterprises, such as poultry, mushroom, goatry, honey bee, etc., and post-harvest processing and value addition and market linkages may be looked for to make the IFS more profitable and sustainable.

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