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Assessment of environmental impact, energetics and productivity of small-farm integrated farming system model under irrigated situation of semi-arid ecosystem of India

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ABSTRACT

Small and marginal farmers in semi-arid regions often practice crop-dominated farming systems, which tend to have low productivity and negative environmental impacts. Transforming these farms into Integrated Farming Systems (IFS) could address multiple challenges. The current study was carried out during 2020–21 to 2021–22 at All India Coordinated Research Project on IFS, Rajasthan Agricultural Research Institute, Durgapura, Rajasthan, to estimate the greenhouse gas (GHG) emission, energy and carbon budgeting of crop-livestock-horticulture based IFS model of 1.45 ha. This IFS model produced mean annual Pearl Millet Equivalent Yield (PEY) of 37,209 kg/year. Among the enterprises, dairy contributed the highest (35.84%) in the mean annual production followed by crops (24.37%). Likewise, the mean annual net return of the IFS model was ₹3,31,853, wherein dairy component contributing the highest (33.09%) followed by crops (29.60%) along with mean annual employment of around 779 man-days. This model consumed 263808 MJ of energy input annually against the total output of 321866 MJ. The model was energy efficient with the mean energy use efficiency of 1.22 and net energy gain of 58058 MJ. This model sequestrated nearly 7324.4 kg CO_2–e as sink through tree components (4978 kg CO_2–e) and incorporated manures or crop residues (2346.4 kg CO_2–e). The results indicated that with diversified cropping (cereals, pulses, oilseed), livestock (dairy, goat, poultry), horticulture (vegetable and mixed orchard) based current IFS model may be a climate smart option for small farmers in the study area to enhance the productivity, profitability, energy use and carbon sequestration to minimize the environmental impact

Keywords: Integrated farming system (IFS), Employment generation, Energy budgeting, GHG emission, Productivity and profitability

In India, more than 85% of farmers are marginal and smallholders practicing subsistence cropping that is vulnerable towards climate change risks having negative impact on natural resources, soil and human health through emission of large scale GHGs, a prime contributor of anthropogenic GHG emissions that is estimated to be approximately 22% (IPCC 2019, Anonymous 2021). The persistence with such farming with irrational use of fertilizers devoid of manurial supplementation has resulted in poor soil health including decline in organic carbon. biota and reduced nutrition supply capacity (Palsaniya *et al*. 2022, Yadav *et al*. 2022) coupled with climate change risks lead towards lower returns for farmers (Yadav *et al*. 2022). Thus, farmers of semi-arid regions under both irrigated and rainfed farming situations need climate resilient alternative farming options having the potential of improving livelihood and nutritional security with ecological perspective (Palsaniya *et al*. 2021) catering diverse needs of farm family.

The Integrated Farming System (IFS) approach by way of diversification and intensification is capable of meeting the objectives of improved and sustained productivity and profitability with better livelihood options under variable climatic challenges particularly for smaller holdings prevailing under semi-arid regions (Garrett *et al*. 2017, Palsaniya *et al*. 2023). The compatible integration of various suitable enterprises leads to synergy exhibited in form of various and diverse positive impacts on production systems benefiting every stakeholder (Dasgupta *et al*. 2021,

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Palsaniya *et al*. 2022). Further, The IFS approach deals and take care of every production factor and production of majority of food and non-food commodities required at farm level in a compatible and synergistic manner enabling sustained utilization and conservation of resources, while addressing the challenges on part of resilience towards climate change and livelihood (Palsaniya *et al*. 2023 and Fatima *et al.* 2023). In this way, this approach not only augment productivity profitability and remunerative regular and higher employment generation but also displays excellence in generating complementarity and synergistic optimization of internal flow among cooperating components, improvement in energy utilization efficiency and higher levels of net energy owing to its more generation on account of improved productivity of system enhancing the viability of farm (Dasgupta *et al*. 2015, Patel *et al*. 2020, Sammauria *et al*. 2020, Fatima *et al*. 2023, Karthik *et al*. 2024).

Therefore, the present study attempted for comprehensive assessment of this IFS model aiming on these objectives in order to generate scientific evidence to facilitate wider adoption of such holistic approach of farming.

MATERIALS AND METHODS

The current study was carried out during 2020–21 to 2021–22 at All India Coordinated Research Project on IFS, Rajasthan Agricultural Research Institute, Durgapura (26° 51´ N, 75° 47´ E; at an altitude of 390 m amsl), Rajasthan. The average annual rainfall received in the region was 563 mm, of which about 90% is received erratically from the latter half of June–September. During the experimentation period, the average monthly maximum and minimum temperature ranged from 19.8–41.6°C and 6.7–29.5°C, respectively. The soil was loamy sand in texture with slightly alkaline in reaction (*p*H 8.1) with 2.1 g/kg organic carbon, 174.5 kg available N, 34 kg available $P_2 O_5$ /ha, 191 kg available $K_2 O$/ha and 7.8 mg/kg available S.

IFS model and its components: The average small farmer holding size in this zone is about 1.45 ha and IFS model was established as a representative small-farm holding IFS model under irrigation situations. The IFS model of 1.45 ha with integration of crops, horticulture, dairy, goatery, poultry, vermicompost, azolla unit and boundary plantation was initiated during 2011. The model had four cropping systems employing cereals, pulses and oilseeds crops in 1.0 ha area i.e. groundnut (RG-510) *fb* wheat (Raj-3765) (0.25 ha), cluster bean (RGC-1038) *fb* barley (RD-2715) (0.25 ha), pearl millet (RHB-173) *fb* gram (CSJ 515) (0.25 ha) and greengram (IPM 2–3) *fb* mustard (RH-749) (0.17 ha). All other recommended package of practices as per crop was followed as and when required. Second enterprise was horticulture (0.25 ha) out of which 0.13 ha was occupied for seasonal vegetables under drip system and 0.12 ha area for a missed orchard dominated by semi-arid fruit trees. Under dairy unit two Gir cows were maintained under stall feeding. Apart from dairy, the IFS model also had goatery (Sirohi breed) and poultry unit (Kadaknath and Rhode Island Red). The animal component of IFS model (cow, goat and poultry) feed with appropriate quantity of chopped palatable green and dry residues and concentrates feed produced in IFS model as per the recommendations. A small unit of vermicompost and compost pits were also established to utilize the available organic waste and excreta into valuable manure.

The component-wise overall average farm production varied therefore, for better comparison, the values of the produce of different enterprises of the IFS model were brought together and converted into Pearl millet Equivalent Yield (PEY) taking into account the prevailing market price of all main and by products.

$$\text{PEY (kg)} = \frac{\text{Yield of IFS component (kg)} \times \text{Price of component (₹/kg)}}{\text{Price of pearl millet (₹/kg)}}$$

Energy indices and their calculation: All inputs such as labour, fuel, electricity, feed, seed, organic manures and inorganic fertilizers, chemicals, machineries, water; and yield components as grains, fruits, vegetables, fodder, meat, manure and other products and by-products were taken into consideration to compute total energy output and input (Yadav *et al*. 2023). The energy coefficients used for assessment of energy outputs and inputs for every item (Meena *et al*. 2022, Yadav *et al*. 2023 and Paramesh *et al*. 2019) and crop production technologies were considered for calculation of following energy indices:

Energy use efficiency (EUE) = Total energy output (MJ)/Total energy input (MJ)

Net energy gain (NEG) = Total energy output (MJ) – Total energy input (MJ)

Energy productivity (EP) = PEY (kg)/Total energy input (MJ)

Direct energy (DE) (MJ) = Labour + Fuel + Electricity

Indirect energy (IE) (MJ) = Seed + Feed + Fertilizers + Chemicals + Machineries + Water

Renewable energy (RE) (MJ) = Labour + Organic Fertilizers + Feed

Non-renewable energy (NRE) (MJ) = Fuel + Electricity + Seed + Fertilizers + Agro-chemicals + Machinery

Estimation of GHG emission and carbon sequestration: The GHGs emissions from different enterprises of the IFS model was performed utilizing GHG estimation tool developed by the ICAR-Indian Institute of Farming Systems Research, Modipuram (Subash *et al*. 2018). This GHG estimator provide data in CO_2 equivalent per unit of crops and per capita for animals as per their GWP specified by IPCC (IPCC 2006).

Estimation of farm profitability and employment generation: The labour employed under each enterprise of IFS model was recorded. The total employment generation in terms of man-days (8 h/day) incurred for each operation under different enterprises were recorded separately and added altogether. The economics of the IFS model was calculated by considering the variable costs only which included human labour, machinery (tractor, plough, planter etc.), feed, fodder, concentrates, seed, fertilizer and pesticide, harvesting and threshing operations under various enterprises. The total cost of the IFS model was estimated by adding the expenditure incurred for different operations under each unit. Finally, net returns of the model was estimated by deducting the cost of cultivation from gross returns and the B:C ratio was also calculated by dividing the net returns with cost of cultivation of the model.

RESULTS AND DISCUSSION

Productivity, profitability and employment generation: The results indicated that altogether from all the component, the IFS model yielded mean PEY of 37,209 kg/year (Table 1). Among the enterprises, dairy contributed the highest in the mean production with the PEY of 13,337 kg/year (35.84% of total production of the model) followed by crops with PEY of 9,066 kg/year (24.37% of total production of the model). After that the IFS model received significant contribution from other components like goatery (5,363 kg PEY/year), vegetable (4,153 kg PEY/year), poultry (2,138 kg PEY/year), fruits (1,457 kg PEY/year), fodder crops (1,020 kg PEY/year), vermicompost (538 kg PEY/year) and boundary plantation (137 kg PEY/year), all together these components contributed 39.79% in the gross production of the IFS model. Likewise, altogether from all the components, the mean annual net return of the IFS model was ₹3,31,853, in which dairy component contributed the highest ₹1,09,821 (33.09%) followed by crops ₹98,243 (29.60%). After that the IFS model received significant contribution from other components like goatery (₹28,920), vegetable (₹49,990), poultry (₹12,149), fruits (₹14,755), fodder crops (₹13,780), vermicompost (₹3,740) and boundary plantation (₹455), all together these components contributed 37.31% in the net returns of the IFS model. The model generated employment of around 779 man-days (Table 1). The total annual man-days were varied from 7 (boundary plantation) to as much as 205 (goatery component). Among the components, dairy generated the highest man-days (205 man-days) followed by goatery (173 man-days), and crops (140 man-days). The higher productivity and net returns under IFS model might be due to integration of various complementary and supplementary enterprises compared to alone cultivation of these components. As the model integrates various diversified enterprises which provide round the year employment to the farmers and same was also evident from the result of the current IFS model (Palsaniya *et al*. 2021, Karthik *et al*. 2024).

Energy input-output relationship: The result indicated that significant deviation in energy usages and energy productivity was observed among different enterprises of IFS model (Table 2). The results indicated that the IFS model consumed 2,63,808 MJ of energy input annually against the total output of 3,21,866 MJ (Table 2). Among the components, dairy consumed highest energy (1,39,952 MJ) followed by goatery (70,339 MJ), crops (32,303 MJ). However, the output energy pattern reflected that crop component produced highest energy (1,82,756 MJ) followed by dairy (42,122 MJ) and fodder unit (40,772 MJ). The model is proved as energy efficient with the mean energy use efficiency of 1.22 and energy gain of 58,058 MJ. The various components wise values of energy use efficiency varied from 0.11 in goatery to as high as 13.80 under boundary plantation. Similarly, the highest energy gain was recorded from crop component (1,50,453 MJ) followed by fodder unit (37,079 MJ). Further, the highest values of energy productivity were recorded from vegetable unit (1.00 kg/MJ) followed by fruits (0.41 kg/MJ). The animal components (dairy, goatery and poultry) showed negative energy gain which might be due to consumption of high energy containing fodder and feed. These findings align with those observed by Palsaniya *et al*. (2021) and Kumar *et al*. (2022).

Overall, the model consumed more of indirect energy (249182 MJ) against direct energy (14,626 MJ) which were around 94.45 and 5.55% of total energy inputs, respectively (Table 2). Likewise, renewable and non-renewable sources shared around 85.70% and 14.30%, respectively. The present study indicated that with integration of diversified crops (cereals, pulses, oilseed, vegetables and fruits), livestock (dairy, goat, poultry) based IFS model was proved to be energy efficient and can be promoted and adopted in the

Table 1 Productivity, profitability and employment generation of small farm IFS model

Enterprises	PEY (kg/year)	Gross return (₹)	Production cost (₹)	Net return (₹)	% share in net returns	Employment (Man-days)	B:C ratio
Crops	9,066	1,76,795	78,552	98,243	29.60	140	2.25
Vegetable	4,153	80,980	30,990	49,990	15.06	78	2.61
Fruits	1,457	28,405	13,650	14,755	4.45	37	2.08
Fodder crops	1,020	19,890	6,110	13,780	4.15	29	3.26
Dairy	13,337	2,60,071	1,50,250	1,09,821	33.09	205	1.73
Goatery	5,363	1,04,580	75,660	28,920	8.71	173	1.38
Poultry	2,138	41,699	29,550	12,149	3.66	75	1.41
Vermicompost	538	10,500	6,760	3,740	1.13	35	1.55
Boundary plantation	137	2,665	2,210	455	0.14	7	1.21
IFS model	37,209	7,25,585	3,93,732	3,31,853	100.00	779	1.84

Table 2 Energy input output relationship and indices of small farm IFS model

Energy indices	Crops	Vegetables	Fruits	Fodder	Cows	Goatery	Poultry	Vermi-compost	Plantation	IFS model
TE input	32303	4152	3516	3693	139952	70339	5999	2250	1604	263808
TE output	182756	13220	6532	40772	42122	8020	4502	1802	22140	321866
EUE	5.66	3.18	1.86	11.04	0.30	0.11	0.75	0.80	13.80	1.22
NEG	150453	9068	3016	37079	-97830	-62319	-1497	-448	20536	58058
EP	0.28	1.00	0.41	0.28	0.10	0.08	0.36	0.24	0.09	0.14
DE	12302	408	541	524	329	118	421	1017	282	14626
IE	20001	3744	2974	3169	139623	5681	5578	1234	1322	249182
RE	4686	1017	556	706	139930	5713	5400	118	62	226108
NRE	27619	3135	2960	2988	22	86	599	2132	1542	37700

TE, Total energy (MJ); EUE, Energy use efficiency; NEG, Net energy gain (MJ); EP, Energy productivity (MJ); DE, Direct energy (MJ); IE, Indirect energy (MJ); RE, Renewable energy (MJ); NRE, Non-renewable energy (MJ).

study area to enhance the productivity, profitability and to minimizes environmental impact especially for small farmers (Palsaniya *et al*. 2021, Babu *et al*. 2020, Babu *et al*. 2023).

GHG emissions and carbon sequestration: GHG emission from each enterprise of the model was estimated based on the daily farm activities. The result showed that the summed GHGs emission from all the components/sources of IFS model was 4,109.7 kg CO_2 –e (Table 3). Among the components, dairy contributed highest in the total GHGs emission (59.49%) followed by field crops (29.59%), goatery (6.90%), horticultural crops (3.09%), fodder crop (0.81%) and poultry (0.12%). The large-scale emission of GHGs from dairy is due to higher emission of methane which is highly is dependent on the digestive system of the animal and the amount and type of feed consumed by it (Paramesh *et al*. 2019). A balanced farming system approach employing increasing the production of forage crops, better management of grazing and intensive use of biodigester and fermented manures like biogas slurry helps in reducing GHG emission are some of the measures to reduce GHG emission by livestock component (Palsaniya *et al*. 2022).

Table 3 GHG emissions and carbon sequestration potential of small farm IFS model (kg CO_2–e)

Enterprises		Component	kg CO_2-e
Carbon sources	Field crops	Green gram-Mustard	200.9
		Groundnut-Wheat	433.4
		Pearl millet-Chickpea	219.0
		Cluster bean-Barley	320.3
	Fodder crops		33.4
	Horticultural (vegetable crops and mixed orchard		127.2
	Dairy		2445.0
	Goatery		283.5
	Poultry		5.2
	Energy used for household		41.8
		Total Source	4109.7
Carbon sink	Boundary plantation		4978.0
	Compost/biomass added		2346.4
	Total sink		7324.4
Net GHG emission of IFS model			-3214.7

A portion of GHG generated in the system could be sequestrated in the plant biomass and stored for an extended period of time through some of the components which is treated as carbon sink for IFS system. The IFS model sequestrated nearly 7324.4 kg CO_2–e as sink through tree components and incorporated manures/ crop residues (Table 3). Net GHG emission from the four IFS models was computed by taking into consideration the role of sources and sink in maintaining the GHG level. It was clear from the results that the model has least environmental impact with net GHGs emission of -32,14.7 kg CO_2–e. The result further suggested that boundary plantation component of the IFS model sequestrated large portion of the carbon (4978 kg CO_2–e) followed by compost and manure (2,346.4 kg CO_2–e). This clearly indicates the role of organic management practices and trees in sequestering carbon. This is in concurrence with the finding that integration of sustainable crop practices and cropping systems could reduce energy use and thereby GHG emission (Babu *et al*. 2020). This is a clear indication of the role of trees in limiting GHG emissions by sequestering carbon and modifying the soil environmental conditions. The roots act as potential sink of carbon in a cropping system. Hence, introduction of more trees in the available space in a farming system could help in mitigating GHG emissions (Babu *et al*. 2020) and also help to maintain crop productivity and ensure food security (Babu *et al*. 2023). Soil can act as source or sink of GHGs emission depending on the type of land use system and management practices adopted. Crop residues and organic manures incorporated into the system could also sequester GHGs and mitigate emission to some extent.

The results of current study indicated that the IFS model yielded 37,209 kg PEY/year in which dairy contributed highest (35.84%) followed by crops (24.37%). Likewise, the mean annual net return of the IFS model was ₹3,31,853, in which dairy component contributed highest (₹1,09,821) followed by crops (₹98,243). The model generated the mean annual employment of 779 man-days. The IFS model sequestrated nearly 7,324.4 kg CO_2–e as sink through tree components and incorporated manures/ crop residues. The model has least environmental impact with net GHGs emission of -32,14.7 kg CO_2–e. The IFS model consumed 2,63,808 MJ of energy input annually against the total output of 3,21,866 MJ. The model is proved as energy efficient with the mean energy use efficiency of 1.22 and energy gain of 58,058 MJ. Overall, it can be concluded that with diversified crops (cereals, pulses, oilseed), livestock (dairy, goat, poultry), horticulture (vegetable and mixed orchard) based current IFS model can be adopted as a climate smart option for small farmers in the study area to enhance the productivity, profitability of the farmers, energy use and carbon sequestration to minimize the environmental impact.

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