



A multi-dimensional analysis of integrated farming system in salt-affected ecologies

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ABSTRACT

The horizontal expansion of the arable areas seems infeasible with dwindling natural resources and declining the average size of landholdings. For harnessing the economic, environmental and social benefits of vertical expansion, the Integrated Farming Systems (IFS) could be instrumental in sustaining the livelihood security of the resource-poor farmers dwelling in the degraded areas. An IFS model of 2 ha was designed covering three major components, namely, grain, horticultural crops and subsidiary at ICAR-Central Soil Salinity Research Institute, Karnal and data from the year 2021–23 was considered for present study. A multi-dimensional analysis covering the financial (net present value, benefit: cost ratio and internal rate of return), soil health (total organic carbon and nitrogen) and environmental (carbon sequestration and greenhouse gas emission) parameters was carried out of an IFS model developed by ICAR-Central Soil Salinity Research Institute, Karnal, Haryana. The findings showed that IFS generates more net return i.e., Rs 66596 than conventional rice-wheat system of equivalent scale (2.0 ha). Additionally, along with improved soil health, the IFS generated lesser (~13.25%) GHG emission as compared to the conventional rice-wheat system. To enhance carbon sequestration in the Integrated Farming System (IFS), more perennial trees should be planted in underutilized areas, especially along boundaries. This is vital for achieving net-zero emissions. Despite its financial viability and environmental benefits, the IFS has low adoption rates. Financial assessments show that economic incentives for initial investments are necessary to encourage wider adoption.

Keywords: Financial analysis, GHG source and sink analysis, Integrated farming system, Salt-affected ecologies, Small and marginal farmers

The increasing population coupled with dwindling resources; the average size of landholdings has declined from 2.28 ha in 1970–71 to 1.08 ha in 2015–16 (GoI 2019). This makes the horizontal expansion of arable land unfeasible, as evident from the fact that since 1970s to till date, the net sown area is hovering around 140 Mha (GoI 2024). Therefore, under such circumstances, the vertical expansion through the Integrated Farming Systems (IFS) is crucial for promoting sustainable crop production and ensuring a reliable source of the livelihoods (Mujahed *et al.* 2023). IFS operate on the principles of the circular economy where the outputs or by products of one or more components are repurposed as inputs for other components, and reduce the dependence on use of external inputs. Thus, makes the production system self-sustaining. Vertical expansion could be an effective

way of managing degraded natural resources (FAO 2024). Furthermore, the concept of IFS involves a comprehensive framework that integrates soil, water, plants and animals, to harness the synergistic interactions among these components for better sustainable and profitable production system than conventional mono-cropping practices (Gill *et al.* 2009).

The concept of IFS is not new for Indian farmers. Historically, Indian farmers have been integrating the multiple enterprises to meet various requirements of food, fibre and fodders. However, the green revolution of the late 1960s and the economic liberalization that began in the early 1990s prompted a gradual concentration on fewer enterprises (Ponnusamy and Devi 2017), for instance rice-wheat system in Haryana and Punjab (Kumar *et al.* 2019). This monocropping of rice-wheat system has various environmental implications (e.g. groundwater depletion, soil health degradation and issues of crop residue burning etc.). Numerous extant studies have shown that integration of mono-crop farming with horticultural crops, agroforestry practices, fisheries, and animal husbandry can significantly contribute to more efficient resource use, boost the income

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of farm households, and strengthen the livelihood security of farmers (Behera and France 2016, Singh *et al.* 2020, Walia and Kaur 2023). Considering the multiple benefits of IFS, concerted efforts were made by the research organizations to design the location-specific IFS models.

In this context, in 2006, a multi-enterprises based IFS model for salt-affected soils was designed by ICAR-Central Soil Salinity Research Institute, Karnal, Haryana at its research farm in 2006. A multi-enterprises model for 2.0 ha land with integration of synergetic components was developed (Singh *et al.* 2009). The envisioned mixed farming systems was expected to safeguard climate change-induced anomalies, including droughts, floods, and temperature variations. Furthermore, it was expected to enhance the productivity and profitability by promoting the efficient use of inputs (water, nutrients, and energy) in smaller agricultural settings. Moreover, it was designed to reduce the cost of cultivation through the synergistic reuse of by-products and residues from various elements within the system, while simultaneously providing a reliable source of income and employment in salt affected soils (Singh *et al.* 2009). With this background, the objective of papers is to assess the financial viability, soil health benefits and environmental benefits of the IFS vis-a-vis the traditional rice-wheat system. The findings of the papers are expected to provide the useful policy insights for the researchers, policy planners and other developmental agencies to facilitate out-scaling of IFS models for better resource use-efficiency and sustainability.

MATERIALS AND METHODS

Outline of the IFS model for salt-affected soils: The Indo-Gangetic area of India is dominated with resource-poor and small and marginal farmers (<2.0 ha) with unequal agrarian structure (Singh *et al.* 2011, Mughal and Sers 2020). In recent past, it has been observed that the crop productivity levels are either declining or stagnant (Jose and Krishna 2021), with associated detrimental environmental

implications, jeopardizing the sustainability of agricultural system (Bishwajit 2014). The key environmental implications include declining soil health and groundwater table, and wide spread crop residue burning etc. (Bhatt *et al.* 2016, Ladha *et al.* 2003). Under these circumstances, to sustain the productivity, profitability and climate resilience while conserving the natural resources, it was hypothesised that IFS could be a viable approach- for the smallholding farmers (Yadav *et al.* 2022, Bano *et al.* 2024). Keeping the multiple benefits of the IFS and average size of landholding (2.43 ha), in the salt-affected soils, for enhancing the water productivity, higher nutrient and energy use efficiency, a 2 ha IFS model was designed covering the three key components, viz. grains, horticultural including fodder and subsidiary enterprises (Supplementary Table 1) at ICAR-Central Soil Salinity Research Institute, Karnal. For present study the data from the year 2021–23 was considered. The total area (2 ha) was divided into three major components as, a) Grain component (1 ha area) subdivided as rice-wheat system (0.4 ha), rice-wheat-moong system (0.2 ha), and maize-wheat-moong system (0.4 ha); b) Horticultural component (0.8 ha) subdivided as guava orchard (0.2 ha), vegetables cultivation (0.2 ha) and fodder production (0.4 ha); and c) Subsidiary component (0.2) considering the dairy and poultry shed and a fish pond.

Financial analysis of integrated farming system: The data are of IFS are being monitored on various aspects such as input usages (fertilizers, seeds, labour etc.) and output produced (crop production, vegetables, fruits and milk production). To show the consistency of the outcomes, in this paper the average values of three years i.e. 2020–21, 2021–22, 2022–23 are shown. The net return was estimated using the following equation:

$$\text{Net return} = \sum_{i=1}^n Y_i \times P_i - \sum_{j=1}^r X_j \times R_j \quad (1)$$

where Y_i is the i th enterprise's output and P_i , prevailing price; and $i = 1 \dots n$, Total numbers of enterprises. X_j and

Table 1 Components of integrated farming system in salt-affected soils

Component	System	Area (ha)
Grain component	Rice-Wheat	0.40
	Rice-Wheat-Moong	0.20
	Maize-Wheat-Moong	0.40
	Sub-total (A)	1.00
Horticultural including fodder	Horticulture (95 Guava trees*)	0.20
	Vegetables	0.20
	Fodder	0.40
	Sub-total (B)	0.80
Subsidiary	Dairy (5 cross breed cattle: 2 milching + 2 dry + 1 calf)	0.20
	Fishery (pond area: 0.1 ha) with production potential of 600k kg.	
	Poultry (25)	
	On pond dykes (Aonla:26; Guava:18 including seasonal vegetables), 8 shade trees .	

*Guava plants are only 3 years old.

R_j is the j th input and its price and $j=1, \dots, r$ is the numbers of inputs used in production. For the logical comparison, the rice-wheat system under the grain component was used as proxy for the traditional rice-wheat system to avoid the effects external factors (e.g. climate variables, differential effects of soil fertility and other and farm management related factors). The financial viability of the IFS was estimated using some key indicators such as IRR (Internal rate of return), NPV (Net present value), BCR (Benefit-cost ratio) and PBP (Pay-back period) using the following equations:

$$BCR = \frac{\sum_{i=0}^t \frac{B_i}{(1+i)^i}}{\sum_{i=0}^t \frac{C_i}{(1+i)^i}} \quad (2)$$

$$NPV = \sum_{i=0}^t \frac{B_i}{(1+i)^i} - \sum_{i=0}^t \frac{C_i}{(1+i)^i} \quad (3)$$

$$IRR = \sum_{i=0}^t \frac{B_i}{(1+IRR)^i} - \sum_{i=0}^t \frac{C_i}{(1+IRR)^i} = 0 \quad (4)$$

where B_i , Benefit occurred in i th period; C_i , Cost incurred in i th period; i , Discount rates taken as 12% and t , life of interventions assumed as 15 years. PBP was computed:

$$PBP = P_1 + \frac{Q}{R} \quad (5)$$

where, P_1 is last period number with a negative cumulative cash flow; Q , Absolute value, i.e., value without negative sign of cumulative net cash flow at the end of the period P ; and R is total cash inflow during the period following period P .

Analysis of soil health parameters: In May 2023, soil samples were drawn out from 0–15 cm and 15–30 cm depth from each system. Soil sample was air-dried and ground to pass through a 2-mm sieve. Total carbon content was measured according to the dry combustion method (Bernard *et al.* 2004) using CHNS Elemental Analyser (EURO EA 3000/IF, Italy). However, CaCO_3 was determined by a calci-meter according to Allison and Moodie (1965). Total inorganic carbon (TIC) content was estimated by multiplying CaCO_3 (%) with a constant, i.e. 0.12 (Singh *et al.* 2022). Total organic carbon (TOC) content was obtained by subtracting the TIC fraction from the total carbon pool (Schumacher 2002). Total nitrogen content is also measured according to the dry combustion method using CHNS elemental analyser.

Source and sink analysis of greenhouse gases: To analyse the greenhouse gases (GHG), viz. methane (CH_4), nitrous oxide (N_2O) and carbon di-oxide (CO_2) source and sink in the IFS model consisting three major components as discussed above. The GHG emission from each IFS component was calculated using the EXCEL model developed by ICAR-Indian Institute of Farming System Research (Subhash *et al.* 2018) considering the activity data (input and operations) and their corresponding emission factors (EFs) based on IPCC factors using below mention equation (6).

$$\text{GHG emission (Mg CO}_2 \text{ eq.)} = A \times \text{Emission factor} \quad (6)$$

where GHG emission is expressed in terms of Mg of CO_2 eq/yr in IFS model. A is the activity data and EF is IPCC emission factor. The similar approach was used for the estimation of GHG emission from the farm yard manure, plant protection chemicals, livestock management, poultry rearing, and duck, and fish pond. The detail GHG emission from conventional rice wheat system was calculated as per the detail methodology of Singh *et al.* (2022) and Fagodiya *et al.* (2023) and for the pulses, the same was computed following Kumar *et al.* (2020). The additional CH_4 and N_2O emission from the enteric fermentation and fertilizers application was converted to CO_2 equivalent by multiplying their GWP (28 for CH_4 and 298 for N_2O). The tree component in case of horticultural component, fruit trees on pond dykes and boundary wall were considered as source of carbon sequestration. The estimation of the tree biomass volume helps in determining the amount of carbon sequestered in tree biomass. Thus, the net GHG emission from the IFS component was calculated using below mentioned equation (7):

$$\text{Net GHG emission} = \text{IFS model total GHG emission} - \text{Carbon sequestered by trees.} \quad (7)$$

RESULTS AND DISCUSSION

Financial analysis of the IFS model: Based on the prevailing prices (TE 2022–23) of the inputs and outputs, the estimated value of the gross returns from the IFS model (2.0 ha) and conventional system (2.0 ha, rice-wheat system) were ₹10,61,161 and ₹4,56,592 respectively (Table 1). Furthermore, at the disaggregate level, the gross returns were ₹2,07,087, ₹1,49,740, and ₹7,04,334 from the grains, horticultural crops, and subsidiary component of the IFS model, respectively and their respective shares were of 19.5, 14.1% and 66.4% of the total gross income. Similarly, the expenditure incurred (cost of inputs including the imputed family labour) was ₹79,287, ₹39,571 and ₹5,70,030, respectively in grains, horticultural crops, and subsidiary component of the IFS model. In the case of the IFS model, the estimate shows that because of multiple components, the expenditure was 4.6 times, however, the gross returns were also 2.3 times that of the CS. As a result, the profit of the IFS model (₹72,273) over the CS (₹3,05,677) was higher to the tune of ₹66,596, which was 1.21 times higher than the CS. Overall, it can be stated the gain from the IFS model was ₹33,298/ha when compared with traditional rice-wheat system.

Financial feasibility analysis of investment on multi-enterprise integrated farming system model (crop-fish-livestock-horticulture components) developed by ICAR-Central Soil Salinity Research Institute, Karnal, Haryana has been carried out with various assumptions. Key assumptions considered are, economic life of 15 years (beyond which cost-return structure will change greatly); discount rate @12% (to take care of time value of money); maximum area in the system will be 2.0 hectare. During the economic life, it is expected that the input cost and output prices will change

Table 2 Net return integrated farming system in salt-affected soils (TE 2022–23)

Component	System	Area (ha)	Gross return (₹)	Expenditure (₹)	Net return (₹)
Grain Component	Rice-Wheat	0.40	91,318	30,183	61,135
	Rice-Wheat-Moong	0.20	47,910	17,142	30,769
	Maize-Wheat-Moong	0.40	67,858	31,962	35,896
	Sub-total (A)	1.00	2,07,087 (19.5)	79,287 (11.5)	1,27,800 (34.3)
Horticultural including fodder	Horticulture	0.20	42,267	6,950	35,316
	Vegetables	0.20	29,140	20,028	9,112
	Fodder	0.40	78,333	12,593	65,740
	Sub-total (B)	0.80	1,49,740 (14.1)	39,571 (5.7)	1,10,169 (29.6)
Subsidiary	Dairy	0.20	4,90,138	4,13,482	76,656
	Fishery		1,80,857	1,42,385	38,472
	Poultry		18,527	9,883	8,643
	Fruits/Mushroom/ Vegetables on dykes		14,813	4,280	10,533
	Sub-total (C)	0.20	7,04,334 (66.4)	5,70,030 (82.7)	1,34,304 (36.1)
Integrated farming system (A+B+C)		2.00	1,06,1161	6,88,889	3,72,273
Conventional RWS		2.00	4,56,592	1,50,915	3,05,677
Net return (System)		2.00			66,596
Net return (per ha)		1.00			33,298

in similar magnitude, opportunity cost for the investment was considered to be the rental value of the land or net return from the prevailing rice-wheat cropping obtained by the farmers. For calculating initial investment of the system, unit cost estimation of NABARD for the Haryana state was considered. With existing input use and output generated the output-input ratios of various enterprises were positive. The initial investment cost of the system was estimated as ₹13,61,820 at current prices (2021–22). The financial analysis indicated that the multi-enterprise system was financially viable in terms of financial viability indicators. The estimated internal rate of return (36%), net present value (₹17,72,406), benefit cost-ratio (1.29) and payback period were 2.77 years (Table 2). Keeping in view of the policy option, sensitivity analysis of system was also carried out with 25% subsidy on the initial investment on the system (Supplementary Table 2). With the subsidy as benefit, the financial criteria were estimated to be 48% (IRR), ₹20,76,284 (NPV), 1.34 (BCR) and payback period reduced to 2.08 years, which indicated that incentives on initial investment will make private investment more attractive.

Soil health parameters: Total organic carbon is considered as a key component of soil health in the terrestrial ecosystem and functions as the central energy source for microorganisms, thus plays a fundamental role in improving the soil structure and ecosystem productivity. Total Organic Carbon (TOC) was analysed in 0–15 cm and 15–30 cm soil depth under all the systems in the year of 2023 (Supplementary Fig. 1a). The highest (0.76%) TOC was reported in the horticulture (guava orchard) system which was at par with fodder (barseem) production and and rice-wheat system at 0–15 cm soil depth. Similarly,

the higher total nitrogen content was reported in the horticulture system and at par with fodder cultivation and rice-wheat system (Supplementary Fig. 1b). The higher TOC and total nitrogen in the guava orchard might be due to higher leaf litter at the soil surface (Datta *et al.* 2015). However, the higher TOC and total nitrogen in the fodder system particularly in berseem field might be due to the nodules formation that will helps in building of TOC in the soils (Kumar *et al.* 2025). Further, the possible reason in rice-wheat system for high TOC content is might be lesser yield penalty under reclaimed sodic soils as compared to other systems.

Greenhouse gases emission and carbon sequestration:

The GHG emission from conventional rice-wheat system and IFS model was calculated based on daily farm activities. The EF assigned to each input such as fertilizer, fuel, electricity, plant protection chemicals, labour, seeds etc. helps in determining the emission from each source of GHG in conventional RWS and from different component of IFS. The GHG emission from conventional RWS was 7592.0 kg CO₂ eq/ha (Table 3) of which total N₂O (direct + indirect) emission contributed 33% followed by electricity consumption for irrigation (27%), fertilizer consumption (23%), CH₄ from the puddled transplanted rice (9%), fuel consumption (5%) etc (Fig. 1a). The total GHG emission from the IFS model was 7422.8 kg CO₂ eq/ha which was at par with the conventional RWS, however, the Net GHG emission was 13.25% lesser (6586.0 kg CO₂ eq/ha).

In IFS model highest (3776.8 kg CO₂ eq/ha) contribution was from livestock rearing which was 27% of Net GHG emission followed by rice-wheat system (20%), maize-wheat-moong system (16%), rice-wheat-moong system

Table 3 Greenhouse gases emission and carbon sequestration from conventional rice-wheat system and different components of the IFS model

Component	System	Area (ha)	kg CO ₂ eq/yr		
			GHG emission	Carbon sequestration	Net GHG emission
Grain Component	Rice-Wheat	0.4	3,036.8		3,036.8
	Rice-Wheat-Moong	0.2	1,729.3		1,729.3
	Maize-Wheat-Moong	0.4	2,506.7		2,506.7
	Sub-total (A)	1	7,272.8		7,272.8
*Horticultural including fodder	Horticulture	0.2	376.8	588.1	-211.3
	Vegetables	0.2	639.4		639.4
	Fodder	0.4	1,437.3		1,437.3
	Sub-total (B)	0.8	2,453.5	588.1	1,865.4
#Subsidiary	Dairy	0.2	3,776.8		3,776.8
	Fishery		1,104.7		1,104.7
	Poultry		103.6		103.6
	Fruits and vegetables on dykes		134.2	1,085.6	-951.4
	Sub-total (C)	2	5,119.3	1,085.6	4,033.7
Integrated farming system (A+B+C)		2	14,845.6	1,673.7	13,171.9
Conventional RWS		2	15,184	0	15,184
Integrated farming system (A+B+C)		1	7,422.8	836.9	6,586
Conventional RWS		1	7,592	0	7,592

(11%), fodder (9%) and fishery (7%) (Fig. 1b). The absolute contribution of maize-wheat-moong system to net GHG emission was higher as compared rice-wheat-moong system and it was mainly because of the area of rice-wheat-moong system was 2-times than the maize-wheat-moong system. However, the relative contribution of maize-wheat-moong system is 17.4% and 27.5% less compared to rice-wheat, and rice-wheat-moong system, respectively. This was mainly because the replacement of rice by the maize significantly reduced CH₄ emission from the soil (Fagodiya *et al.* 2020). The perennial trees in guava orchard as well as fruits and shed trees on dykes are helpful in carbon sequestration. The total amount of carbon sequestration in IFS model is 1673.72 kg CO₂ eq/yr of which shed trees contributed 45% (752.1 kg CO₂ eq/ha) which is 45%, followed by guava orchard (35%), aonla tress on dykes (18%) and guava tress on dykes (2%) (Supplementary Table 3). Although the shed tree is least in numbers (8 nos.) still their contribution is highest and it mainly because highest biomass. At the same time the guava tress in orchards was 95 in numbers still their contribution is only 35% and it is mainly because the guava orchard is only 3 years old and having low biomass per tree. It is clearly indicating the roles of perennial trees in sequestering atmospheric carbon and storing it within the system. Therefore, in order to make the present IFS model carbon neutral, there is need to improve the carbon sequestration through the integration of the more numbers of perennial trees either through agroforestry system planting on boundaries and dykes. This is in the concurrence with the finding that integration of sustainable crop practices and cropping systems along with the agroforestry, horticulture and livestock could reduce the energy use and thereby the GHG emission (Camargo *et al.* 2013).

Constraints in adoption of IFS: stakeholders' perspective: Integrated Farming Systems (IFS) provide a range of benefits, notably increased productivity, enhanced resource efficiency, and improved resilience to climate variability. By combining different agricultural activities, IFS ensures that the by-products of one component are

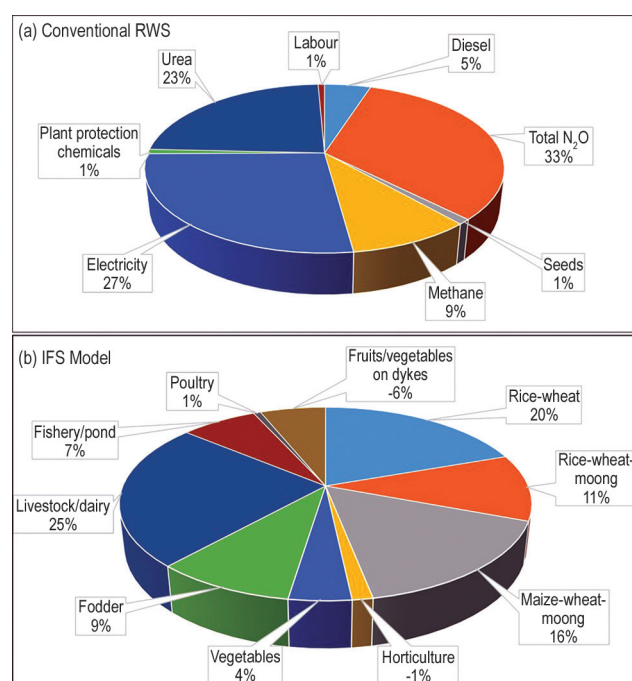


Fig. 1 Percent contribution of (a) different sources to GHG emission in conventional rice-wheat system, and (b) different component of IFS model to net GHG emission. Here minus values in horticulture and fruits on dykes showed net GHG emission (GHG emission-carbon sequestration).

utilized as inputs for another, thereby optimizing resource utilization. This model has been effective in raising overall farm income and reducing the risks that are often associated with monoculture systems (Meena 2022). Several factors play a crucial role in determining the adoption rate of integrated farming systems. Important elements include the socio-economic environment, educational attainment, and access to financial resources. Many smallholder farmers encounter financial challenges that hinder their ability to invest in new agricultural practices or technologies (Priya and Singh 2024). In spite of the seemingly multiple benefits and higher income still the adoption of the IFS model is very low (Bosma *et al.* 2012, Raghavendra *et al.* 2024).

Results from the stakeholders' perspective shows that small-size of land holding is perceived as major constraints by small and marginal farmers as compared to medium to large farmers (Supplementary Table 4). This can be attributed to fact that smallholders prefer rice-wheat system for ensuring their food security, and assured income due to robust market and price support in Haryana and Punjab. On the contrary, medium and large farmers were of the opinion that such IFS model is labour intensive, and scope of mechanization is comparatively less as compared to rice-wheat system. All types of the farmers almost equally expressed their views about the IFS being more efforts and knowledge intensive and youth of their families are reluctant to opt the farming as their source of livelihood. Furthermore, the access to market and higher volatility in prices of vegetable and fruits is also hindering the adoption of the IFS model.

Integrated farming system (IFS) for the smallholder farmers (2.0 ha) dwelling in the salt-affected soils. It was found to be a sustainable on all the aspects of the sustainability, which is financially viable and, ensure the environmental security. IFS is generating more net return (₹66,596) than the dominant conventional rice-wheat system. The results showed that parameters of the soils health have improved over the time. The GHG emissions from IFS model are found be lesser (13.25%) than the conventional rice-wheat system. However, to harness the full potential of the carbon sequestration in the existing IFS model, there is a need to add more numbers of perennial trees on the less utilized space, particularly the boundary plantation. This will generate extra income and will be helpful to achieve the net-zero emission in Indian agriculture by 2050. In spite of the being financially viable and generating environmental benefits, the low adoption of the IFS is matter of the concerns. The financial viability analysis with and without subsidy reinforces the provision of the economic incentives on relatively initial investment has the potential for boosting prospects for its higher and wide-spread adoption.

REFERENCES

- Allison L E and Moodie C D. 1965. Carbonate. *Methods of soil analysis: Part 2. Chemical and microbiological properties*, 9.2, pp. 1379–96. Norman A G (Ed). American Society of Agronomy, Madison, Wisconsin.
- Bano N, Yadav B and Kumari N. 2024. Livelihood security of small and marginal farm families, adopted conventional and integrated farming system: A comparative analysis. *Journal of Community Mobilization and Sustainable Development* **19**: 187–97.
- Behera U K and France J. 2016. Integrated farming systems and the livelihood security of small and marginal farmers in India and other developing countries. *Advances in Agronomy* **138**: 235–82.
- Bernard B B, Bernard H and Brooks J M. 2004. Determination of total carbon, total organic carbon and inorganic carbon in sediments. TDIB books International/B&B Lab Inc., Texas.
- Bhatt R, Kukal S S, Busari M A, Arora S and Yadav M. 2016. Sustainability issues on rice-wheat cropping system. *International Soil and Water Conservation Research* **4**(1): 64–74.
- Bishwajit G. 2014. Promoting agricultural research and development to strengthen food security in South Asia. *International Journal of Agronomy* **2014**: 1–6.
- Bosma R H, Nhan D K, Udo H M and Kaymak U. 2012. Factors affecting farmers' adoption of integrated rice-fish farming systems in the Mekong delta, Vietnam. *Reviews in Aquaculture* **4**(3): 178–90.
- Camargo G G T, Ryan M R and Richard T L. 2013. Energy use and greenhouse gas emissions from crop production using the farm energy analysis tool. *BioScience* **63**(4): 263–73.
- Datta A, Basak N, Chaudhari S K and Sharma D K. 2015. Soil properties and organic carbon distribution under different land uses in reclaimed sodic soils of north-west India. *Geoderma Regional* **4**: 134–46.
- Fagodiya R K, Pathak H, Bhatia A, Jain N and Gupta D K. 2020. Global warming potential and its cost of mitigation from maize (*Zea mays*)-wheat (*Triticum aestivum*) cropping system. *The Indian Journal of Agricultural Sciences* **90**(1): 69–74.
- Fagodiya R K, Singh A, Singh R, Rani S, Kumar S, Rai A K, Sheoran P, Chandra P, Yadav R K, Sharma P C and Biswas A K. 2023. The food-energy-water-carbon nexus of the rice-wheat production system in the western Indo-Gangetic Plain of India: An impact of irrigation system, conservation tillage and residue management. *Science of the Total Environment* **860**: 160428.
- FAO. 2024. Integrated production systems and climate change, Food and Agriculture Organization. <https://www.fao.org/climate-smart-agriculture-sourcebook/production-resources/module-b5-integrated-production-systems/chapter-b5-1/en/>
- Gill M S, Singh J P and Gangwa K. 2009. Integrated farming system and agriculture sustainability. *Indian Journal of Agronomy* **54**(2): 128–39.
- GoI. 2019. All India Report on Number and Area of operational holdings, agriculture census division, Department of Agriculture, Co-Operation and Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Government of India.
- GoI. 2024. *Agricultural statistics at a glance 2023*. Ministry of Agriculture & Farmers Welfare, Department of Agriculture and Farmers Welfare, Economics, Statistics and Evaluation Division, Government of India.
- Jose and Krishna V V. 2021. Whether Indian wheat? productivity plateau, spatial heterogeneity, and R&D targeting. *Review of Agrarian Studies* **11**(1): 22–47.
- Kumar S, Jha G K, Singh D R and Biswas H. 2020. Economic incentives for sustainable legume production in India. *Current Science* **119**(7): 1184–89.

- Kumar S, Sharma D K, Singh D R, Biswas H, Praveen K V and Sharma V. 2019. Estimating loss of ecosystem services due to paddy straw burning in North-west India. *International Journal of Agricultural Sustainability* **17**(2): 146–57.
- Kumar S, Singh M, Kumar S and Rajeev 2025. Changes in root nodules dynamics under mixed cropping with varying nutrient management of berseem crop and succeeding fodder cowpea. *Journal of Plant Nutrition* **48**(4): 617–38.
- Ladha J K, Dawe D, Pathak H, Padre A T, Yadav R L, Singh B, Singh Y, Singh Y, Singh P, Kundu A L and Sakal R. 2003. How extensive are yield declines in long-term rice–wheat experiments in Asia? *Field Crops Research* **81**: 159–80.
- Meena L R. 2022. Integrated farming system models development for small and marginal households for sustainable production and livelihood improvement in India: An overview. *Medicon Agriculture and Environmental Sciences* **3**: 05–18.
- Mughal M and Sers C F. 2020. Cereal production, undernourishment and food insecurity in South Asia. *Review of Development Economics* **24**(2): 524–45.
- Mujahed B A, Singh J and Saqib A. 2023. Integrated farming system: Trends, advantages and constraints-A review. *RASSA Journal of Science for Society* **5**(2–3): 65–69.
- Ponnusamy K and Devi M K. 2017. Impact of integrated farming system approach on doubling farmers' income. *Agricultural Economics Research Review* **30**: 233–40.
- Priya and Singh S P. 2024. Factors influencing the adoption of sustainable agricultural practices: a systematic literature review and lesson learned for India. *Forum for Social Economics* **53**(1): 1–17.
- Raghavendra K J, John J, Jacob D, Rajendran T, Prusty A K, Ansari M A, Ravisankar N, Kumar S, Singh R, Shamim M, Punia P, Nirmal, Meena A L, Kashyap P, Shivaswamy G P and Dutta D. 2024. Unraveling determinants of integrated farming systems adoption for sustainable livelihood and dietary diversity. *Frontiers in Nutrition* **11**: 1264658.
- Schumacher B A. 2002. Methods for the determination of total organic carbon (TOC) in soils and sediments. U S Environmental Protection Agency, Washington D C, USA.
- Singh G, Jat H S, Kumar A, Sekhawat K, Yaduvanshi N P S, Tripathi R S, Batra L. Pandey, R S, Sharma P C, Chaudhari S K, Singh S K, Kundu S S, Sirohi N S, Mohan S, Singh D and Kailash 2009. Eco-friendly integrated multi-enterprise model for livelihood security in small farm holdings, pp. 28. Central Soil Salinity Research Institute, Karnal-Haryana, India.
- Singh R, Singh A, Sheoran P, Fagodiya R K, Rai A K, Chandra P, Rani S, Yadav R K and Sharma P C. 2022. Energy efficiency and carbon footprints of rice-wheat system under long-term tillage and residue management practices in western Indo-Gangetic Plains in India. *Energy* **244**: 122655.
- Singh R D, Dey A and Singh A K. 2011. *Vision-2030*. pp. 26. ICAR Research Complex of Eastern Region, Patna.
- Singh V K, Rathore S S, Singh R K, Upadhyay P K and Shekhawat K. 2020. Integrated farming system approach for enhanced farm productivity, climate resilience and doubling farmers' income. *The Indian Journal of Agricultural Sciences* **90**(8): 1378–88.
- Subash N, Dutta D and Ravisankar N. 2018. *IFS-GHG Estimation Tool Ver. 1.0. A greenhouse gases estimation tool for integrated farming system models*; AICRP-IFS, ICAR-IIFSR: Modipuram, Meerut, India.
- Walia S S and Kaur T. 2023. Sustainable Rural Livelihood Security Through IFS. *Basics of Integrated Farming Systems*, pp. 113–55, Walia S S and Kaur T. (Eds). Springer Nature Singapore.
- Yadav G, Jat H S, Raju R, Yadav R K, Singh S K, Chaudhari S K and Sharma P C. 2022. Enterprise mix diversification: An option for ecologically sustainable food and nutritional security of small holders in Indo-Gangetic plains. *International Journal of Agricultural Sustainability* **20**(1): 31–41.