Indian Journal of Agricultural Sciences **95** (3): 266–271, March 2025/Article
https://doi.org/10.56093/ijas.v95i3.163028

Integrated farming system approaches for sustainable and climate resilient agriculture

ADIKANT PRADHAN[1]*, S AGRAWAL[1], S MALAIYA[2], V NAYAK [1] and AMARNATH[1]

Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh 492 012, India

Received: 30 December 2024; Accepted: 18 February 2025

ABSTRACT

A field experiment was conducted during 2022 and 2023 at the Agricultural Research cum Instructional Farm, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh under All India Coordinated Research Project on Integrated Farming System (IFS) to study the feasible IFS model for sustainable agriculture. The experiment was laid out in a split-plot design (SPD) with three replications. Rice (*Oryza sativa* L.) fallow systems recorded the lowest Rice Equivalent Yield (REY) which was improved with rice-sweet corn (*Zea mays* L.)-tomato (*Solanum lycopersicum* L.) + coriander (*Coriandrum sativum* L.) cropping (13254 kg/ha) being significantly superior over remaining treatments. The rice-sweet corn-tomato + coriander system had 245.03%, 303.04%, 231.9% and 308.13% higher REY over rice-french bean (*Phaseolus vulgaris* L.)-groundnut (*Arachis hypogaea* L.); rice-berseem (*Trifolium alexandrinum* L.)-sorghum [*Sorghum bicolor* ssp. bicolor (L.) Moench]; rice-garden pea (*Pisum sativum* L.)-cowpea [*Vigna unguiculata* (L.) Walp.] and rice-fallow systems, respectively. Water productivity was 1.96 kg/m^3 in mushroom component as low energy use system among recycled manures, whereas poultry restored more soil organic carbon (0.77%) over initial (0.63%). The lower emission of green house gas (-126 kg CO_2 equivalent) was in mushroom over rest of recycled manures while among cropping system, rice-sweet corn-tomato + coriander had lower emission of GHGs. The poultry recycled manure incurred 37355 MJ with output of 90475 MJ, however it also generated more employment (311 man-days). Gross return (₹21,681), net return (₹12,231) and employment generation (212 man-days) of rice-sweet corn-tomato+coriander was higher followed by rice-french bean-groundnut adopted for family nutrition.

Keywords: Dairy components, Farm yard manure, Integrated Farming System, Vermicompost

Small farmers are less likely to practice modern farming because of less investment and risk taking capacity (Singh and Toor 2005). Conventional agriculture that has been carried out so far has caused various problems including increased costs of energy-based inputs, reduced farm income, economic and ecological problems i.e. poor ecological diversity, soil erosion, and both soil and water pollution. Small and marginal farmers are less in practicing modern farming owing to less investment and risk taking capacity (Singh and Toor 2005). The Integrated Farming System (IFS) is one of the best options for enhancing the well-being of smallholders and ensuring sustainable livelihoods. It not only enhances the nutritional and economic standing of farming families but also boosts employment opportunities and optimizes the use of agricultural resources. The IFS integrates agricultural and animal enterprises, which is drawing fresh attention from marginal, small, and medium farmers who cultivate less than one hectare. The fundamental principle of integration is that the output of each company should serve (Behera and France 2016) as input for another, fostering complementarity among them (Gill *et al.* 2009). Emphasizing enhanced ecosystem functioning, including nutrient recycling, soil formation, and fertility improvement, the IFS strategy advocates for ecological intensification and aims to minimize reliance on anthropogenic inputs (Bell and Moore 2012).

In South Asia, nearly 15 million ha (Mha) of cultivated area remains fallow annually, and about 11.6 Mha area lies in India (Ghosh *et al.* 2016, Gumma *et al.* 2016), and 80% area falls under rice-fallow (9.70 Mha) in eastern India (Ali *et al.* 2014, Singh *et al.* 2017, Kumar *et al.* 2018). The important parameter and major issue in developing IFS is food and nutrients security as well as sustainability of farmers. IFS consists of many resources conserving practices that purposefully design to achieve feasible profits and high sustained production through reducing the negative effects of integration of resources and conserving environment (Lal and Miller 1990, Porpavai and Marimuthu 2018). Developing countries like India mainly focuses on sustainable development through better

[1]All India Coordinated Research Project on IFS, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh; [2]Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh. *Corresponding author email: adi19agro@gmail.com

agricultural practices addressing socio-economic as well as environment sustainability together. IFS is often risk proofing, if managed efficiently, they provide synergisms within enterprises with different produces in environmental safety (Singh *et al.* 2007).

According to effects of climate change scenario, losses of grain yield could be 35% for rice, 20% for wheat and 60% for maize, which show direct effect to livestock production by food scarcity and challenge of climatic change (Kakamoukas *et al.* 2021). Farming systems has unique character of temporal and spatial combination of crops, livestock, fishery, and allied activities in a single unit of farm (Paramesh *et al.* 2021). IFS system obtained more productivity of 32.46 t/ha and net returns of ₹3,24,797.89 which is 1.6 and 3.0 times higher, respectively in comparison to conventional systems (Shanmugam *et al.* 2024). The IFS integrates agricultural and animal enterprises, which draws new innovational approach for marginal, small, and medium farmers (Behera and France 2016). IFS emphasize in enhancing nutrient recycling, soil formation, and fertility improvement, also advocates for ecological intensification to minimize anthropogenic inputs (Bell and Moore 2012). These systems can be efficient and remunerative, but they eventually end up with causing environmental problems, depletion of soil nutrients, affecting soil biota, and leading to higher cost of production (Devendra and Thomas 2002). Rice based cropping system supports almost 300 million people in 40 million hectares of Asia lands (FAO 2002, Ray *et al.* 2016). For resource use efficiency, input substitution and designing a sustainable cropping, systematic crop production with managing natural resources is a possible way (Pretty *et al.* 2018). Keeping above views in mind, present investigation has been framed to know feasible IFS model for sustainable agriculture.

MATERIALS AND METHODS

A field experiment was conducted during 2022 and 2023 at the Research cum Instructional Farm, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh under trial of All India Coordinated Research Project on Integrated Farming System (IFS). The soil was characterized by sandy loam, acidic in nature (6.25), while 312 kg/ha N, 24.2 kg/ha available P_2O_5 and 269.05 kg/ha available K_2O was present in experimental site. The experiment was laid out in a split-plot design (SPD) with three replications. Main plot treatments included recycled manures from Farmyard Manure (FYM), compost manure, vermicompost along with a control (no recycled manure). The recycled manure was prepared by composting and digestible organic wastes of farm. The recycled manures were used in rice and given as per treatments within farming system. Rice based cropping system was laid out for rice (vs *Protazin*)-french bean (vs *Serengeti*)-groundnut (vs *CGG-1*) as family nutrition, rice (vs *Badsaahbhog*)-berseem (vs *BL-180*)-sorghum (vs *CSH-16*) as livestock nutrition, rice (vs *Hybrid US-312*)-sweet corn (vs *Sugar75*)-tomato (vs *Saaho-TO 3251*) + coriander (vs *Chandrahasini*) as income enhancement, rice (vs *Dubraj*)-garden pea (vs *Goldie*)-cowpea (vs *Kashi Kanchan*) as soil health and rice-fallow was local control in sub plots. The rice-based croppings were grown under assured irrigation. The rice-grain-equivalent yield was worked out as suggested by Jayanthi (1995), composting was prepared using straw of the crops, while fodder crops and rice husk were ingredient of feed for livestock.

Water productivity (WP) is calculated by dividing the crop productivity (CP) in kg/m^2 with the crop water use (CWU) in m^3/m^2. The determination of soil organic carbon was based on Walkley-Black chromic acid wet oxidation method. The resource inputs and outputs converted from physical to energy unit (MJ) through various published conversion coefficients (Table 1). Employment generation (man-days) was a measure of the number of days provided employment to the people.

Table 1 Resource input and their energy equivalent

Resource input	Unit	Equivalent (MJ/unit)	Reference
Labour	h	1.96	Singh and Mittal (1992)
Diesel fuel	l	47.87	Singh and Mittal (1992)
Electricity	kWh	3.6	Ozkan *et al.* (2004)
Nitrogen (N)	kg	60.6	Singh and Mittal (1992)
Phosphorous (P_2O_5)	kg	11.1	Singh and Mittal (1992)
Potassium (K_2O)	kg	6.7	Singh and Mittal (1992)
Zinc sulphate ($ZnSO_4$)	kg	20.9	Singh and Mittal (1992)
Manure/FYM	kg	0.3	Taki *et al.* (2012)
Vermicompost	kg	0.5	Ram and Verma (2015)
Farm machinery	kg	62.7	Tuti *et al.* (2012)
Herbicides	kg	254.45	Pimentel (1980)
Insecticides	kg	184.63	Pimentel (1980)
Water	m^3	1.02	Tuti *et al.* (2012)
Mineral feed	kg	2	Wells C (2001)
Rice, french bean, groundnut, berseem, sorghum sweet corn, tomato, coriander, garden pea and cowpea	kg	14.7	Singh and Mittal (1992)
Berseem	kg	10	Singh and Mittal (1992)
Chick (poultry)	kg	4.56	Gopalan *et al.* (1971)
Mushroom	kg	1.62	Salehi *et al.* (2014)
Manure by-product (dry mass)	kg	0.30	Taki *et al.* (2012)
Straw (crops)	kg	12.5	Singh and Mittal (1992)

Energy equivalent calculated from energy equivalent of the product (Gopalan *et al.* 1971) plus 0.5 (Singh and Mittal 1992).

Statistical analysis: The statistic data were analyzed by applying "Analysis of Variance" (ANOVA) technique of split plot design (Gomez and Gomez 1984). The significance of different sources of variations was tested by error mean square of 'F' test at probability level 0.05. Standard error of mean (SEM±) and critical difference (CD) (P=0.05) level of significance were worked out for each character to compare the difference between the treatment means by pooled analysis of two year data.

RESULTS AND DISCUSSION

Performance of cropping systems: The productivity of cropping systems was significantly influenced with different crops incorporated in the system and their pooled mean were presented in Table 2. Rice-sweet corn-tomato+coriander grown in sequence for income enhancement was found significant among the cropping systems, and rice equivalent yield of rice-french bean-groundnut was also more being at par with rice-garden pea-cowpea. The lowest productivity was noted under rice-fallow. Rice-sweet corn-tomato +coriander had higher (20,699 kg/ha) Rice Equivalent Yield (REY) followed by rice-garden pea-cowpea (17,515 kg/ha). Rice-berseem-sorghum (17,799 kg/ha) became more feasible for livestock nutrition. Rice-sweet corn-tomato+coriander performed better than other cropping systems regardless recycled manures due to combination of high value crops in sequence, whereas recycling of manure in soil accelerated overall production and income. The higher rice equivalent yield (13,254 kg/ha) was obtained by rice-sweet corn-tomato +coriander cropping system with application of farm yard manure owing to more remunerative crops in sequence and regular supply of nutrient supported a lot to the cropping as conformity with the finding of Bouman (2007).

Table 2 Productivity and REY of integrated farming systems (mean data over 2 years)

Farming systems	Component productivity (kg/ha)			REY (kg/ha)
	Crop	Poultry	Mushroom	
Rice-french bean-groundnut as family nutrition	4311 (37%)	3965 (34%)	3521 (30%)	11797
Rice-berseem-sorghum as livestock nutrition	6852 (38%)	5845 (33%)	5102 (29%)	17799
Rice-sweet corn-tomato+coriander as income enhancement	8012 (39%)	6584 (32%)	6103 (29%)	20699
Rice-garden pea-cowpea	6522 (37%)	5672 (32%)	5321 (30%)	17515
Rice-fallow	3526	-	-	3526
Parameters	C	CS	I	
CD (P=0.05)	1165	741	1005	

C, Component; CS, Cropping system; I, Interaction; REY, Rice equivalent yield.

The highest REY was recorded with rice-sweet corn-tomato+coriander (13,118 kg/ha) which was significantly superior over rest of treatments. However, rice-french bean-groundnut and rice-garden pea-cowpea were on par with each other and lowest REY was noted under rice-fallow (2,257 kg/ha). Recycled manures were not found significant different but maximum value attained by farm yard manure (6,125 kg/ha). The higher REY was with rice-sweet corn-tomato +coriander due to year round crop production and synergistic effect of residual on overall productivity, similar finding was quoted by Paramesh *et al* (2021). Interaction of rice-sweet corn-tomato+coriander attained maximum rice equivalent yield when farm yard manure was added in cropping system which was significant on remaining combinations (Table 3). However, more number of crops and plus vegetable in cropping system enhanced yield due to higher prevailing market price.

Component productivity: Rice fallow had lowest component productivity in cropping systems, which gradually increased as more crops were grown and gave higher component productivity in Rice-sweet corn-tomato+coriander. Rice-berseem-sorghum and rice-sweet corn-tomato+coriander were similar in attaining component productivity under cropping system. The highest REY was obtained under rice-sweet corn-tomato+coriander sequence and rice-berseem-sorghum and rice-garden pea-cowpea systems were found statistically similar. The rice-sweet

Table 3 Effect of recycled manures and cropping system on REY

Cropping system	Recycling manure				Mean
	Farm yard manure (FYM)	Compost manure	Vermicompost	Control (No recycled manure)	
Rice-french bean-groundnut as family nutrition	5623	5245	5984	4562	5354
Rice-berseem-sorghum as livestock nutrition	4415	4256	4657	3987	4329
Rice-sweet corn-tomato +coriander as family income	13254	12045	12451	14721	13118
Rice-garden pea-cowpea	5324	6235	5326	5742	5657
Rice-fallow	2007	2692	2008	2321	2257
Mean	6125	6095	6085	6267	
Parameters	C	CS	I		
CD (P=0.05)	NS	312	986		

C, Component; CS, Cropping system; I, Interaction; REY, Rice equivalent yield (kg/ha).

corn-tomato+coriander system had 245.03%, 303.04%, 231.9% and 308.13% higher REY over rice-french bean-groundnut; rice-berseem-sorghum; rice-garden pea-cowpea and rice-fallow systems, respectively. The productivity was a consequence of higher yield of tomato and fruits/plant than other rice-based cropping. Moreover, as inputs of diesel and electrical had maximum energy in rice-sweet corn-tomato+coriander, it showed higher energy input farming among the cropping system. Balusamy (1994) also inferred that inclusion of a vegetable in the rice-based sequence recorded the highest yield as well as cost. Padhi (1993) opined that inclusion of cowpea not only enhanced the production of the crops but also contributed for higher total production. Among the recycled manures, higher grain yield was recorded in recycled rice straw with mushroom-spent substrate and followed by recycled poultry manure.

Gross return (₹21,681), net return (₹12,231) and employment generation (212 man-days) of rice-sweet corn-tomato+coriander was higher followed by rice-french bean-groundnut adopted for family nutrition (Supplementary Table 1). However, rice-french bean-groundnut and rice-garden pea-cowpea were similar in economical fulfillment. The lowest was noticed with rice-fallow cropping due to single crop grown year round crop cycle. Among recycled manures, Farm Yard Manure (FYM) had maximum gross return of ₹12,543/- followed by compost manure and similar trend was also observed in net return and employment generation.

Key performance indicators: The key performance of IFS model indicated by water, soil carbon, energy, environmental resources and employment generation (Supplementary Table 2). Water productivity was recorded 1.96 kg/m^3 with mushroom recycling, and soil organic carbon increased 0.77% in poultry recycling over initial carbon of 0.63%. Even poultry recycled triggerred higher input and out energy and simultaneously employment generation due to high potent litter of poultry contributed in the farming system. On the demand side, limiting food waste is an effective way to reduce emissions. Changes in a diet less reliant on animal products such as plant-based diets, are also effective (Anonymous 2022). Green house emission was reduced more with mushroom (-126 kg CO_2 equivalent) as compared to farm yard manure and poultry. But cropping systems had greater reduction in emission of carbon dioxide as compared to recycled manures. Moreover, rice-sweet corn-tomato+coriander proved more environmental positive in managing emission of CO_2 followed by rice-garden pea-cowpea (-767 kg CO_2 equivalent) and rice-berseem-sorghum (-649 kg CO_2 equivalent). CO_2 is re-emitted into the atmosphere by plant and soil respiration in the later stages of crop growth, causing more greenhouse gas emissions (Sharma *et al.* 2021).

Rice-sweet corn-tomato+coriander as family income had higher water productivity (kg/m^3), energy input (MJ), energy output (MJ) and employment generation (man-days) whereas initial soil organic carbon (%) was increased from 0.78–0.88% compared to other cropping system owing to more number of legumes included in the cropping sequence. The highest reduction in emission of greenhouse gas was captured by growing rice-sweet corn-tomato+coriander as source of income where more bio-mass was generated over rest of cropping systems. Opportunities for improving crop water productivity mainly lie in choosing practices, water efficient crops, and ensuring ideal agronomic conditions for crop production (Kijne *et al*. 2003, Bouman 2007, Rockstrom and Barron 2007). Higher demand for food, nutritional and health security has intensive use of energy inputs in agricultural system leading to threat along with environment, so energy budgeting in agriculture is very crucial to get sustainability and profitability and to recognize the best performing model that can be adopted among farmers (Erdal *et al*. 2007, Taki *et al*. 2012, Soni *et al*. 2013).

Area share in different component showed remarkable change in IFS model when cropping sustem, dairy and vermicomposting were included, the higher share was incurred in cropping system which contributed more than 70% (R^2=0.78) followed by vermicomposting and then dairy. Whereas income wise shares were reversed with dairy and vermicomposting, hence dairy income was more than vermicompost in contribution (R^2=0.88) in system (Fig. 1 and 2).

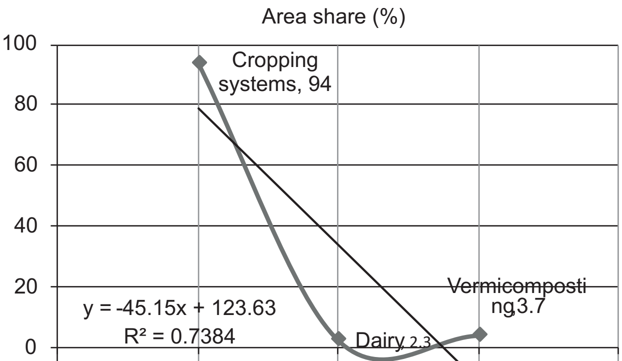

Fig. 1 Area share of IFS model.

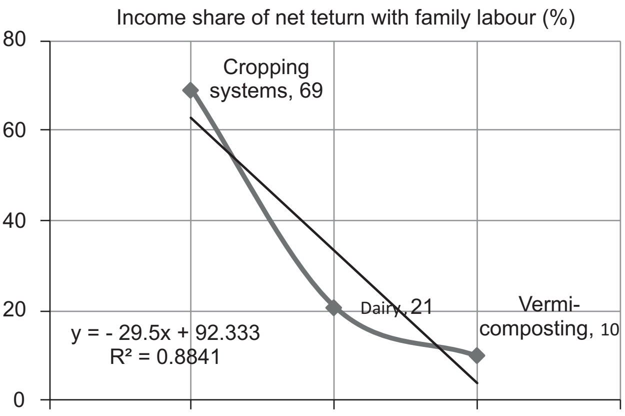

Fig. 2 Income share of IFS model.

Rice-sweet corn-tomato+coriander with application of farm yard manure had higher rice equivalent yield (17,799 kg/ha), water productivity (kg/m^3), energy use and employment generation. Initial soil organic carbon (%) was increased from 0.78–0.88% in rice-garden pea-cowpea cropping and rice-garden pea-cowpea also curbed the emission of CO_2 (-767 kg CO_2 eqv).

REFERENCES

Ali M, Ghosh P K and Hazra K K. 2014. Resource conservation technologies in rice fallow. *Resource Conservation Technology in Pulses*, pp. 83–88. Ghosh P K, Kumar N, Venkatesh M S, Hazra K K and Nadarajan N (Eds). Scientific Publishers, Jodhpur, Rajasthan, India.

Balusarny M and Shanmugasundararn V S. 1994. Integrated farming system studies in A R S Bhavanisagar. *Lecture Notes of Summer Institute on Integrated Farming Systems Research Management for Sustainable Agriculture*, pp. 270–77.

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.

Bell L W and Moore A D. 2012. Integrated crop–livestock systems in Australian agriculture: Trends, drivers and implications. *Agricultural Systems* **111**: 1–12.

Bouman B. 2007. A conceptual framework for the improvement of crop water productivity at different spatial scales. *Agricultural Systems* **93**: 43–60.

Deep S G, Ibrahim S M, Umer S, Mansi J and Ritika C. 2021. Exploring the nexus between agriculture and greenhouse gas emissions in BIMSTEC region: The role of renewable energy and human capital as moderators. *Journal of Environmental Management* **297**: 113316.

Devendra C and Thomas D. 2002. Small holder farming systems in Asia. *Agricultural Systems* **71**(1-2): 17–25.

Erdal G, Esengun K and Guduz O. 2007. Energy use and economic analysis of sugar beet production in Tokat province of Turkey. *Energy* **32**: 34–41.

FAO. 2002. Rural Asia-Pacific: Inter-disciplinary strategies to combat hunger and poverty. Rice-based livelihood-support systems. RAP Publication (FAO).

Ghosh P K, Hazra K K, Nath C P, Das A and Acharya C L. 2016. Scope, constraints and challenges of intensifying rice (*Oryza sativa* L.) fallows through pulses. *Indian Journal of Agronomy* **61**(4th IAC Special Issue): S122–28.

Gill M S, Singh J P and Gangwar K S. 2009. Integrated farming system and agricultural sustainability. *Indian Journal of Agronomy* **54**(2): 128–39.

Gomez K A and Gomez A. 1984. *Statistical Procedure for Agricultural Research*. John Wiley and Sons.

Gopalan C, Shashtry B V R and Balasubramanium S C. 1971. *Nutritive Value of Indian Foods*, pp. 47–58. National Institute of Nutrition (ICMR) press, Hyderabad.

Gumma M K, Thenkabail P S, Teluguntla P, Rao M N, Mohammed I A and Whitbread A M. 2016. Mapping rice-fallow cropland areas for short-season grain legumes intensification in South Asia using MODIS 250 m time-series data. *International Journal of Digital Earth* **9**(10): 981–1003.

Jayanthi C. 1995. 'Sustainable component linkage and resource re-cycling to lowland integrated farming systems'. PhD Thesis, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu.

Kakamoukas G, Sarigiannidis P, Maropoulos A, Lagkas T, Zaralis K and Karaiskou C. 2021. Towards climate smart farming - A reference architecture for integrated farming systems. *Telecom* **2**(1): 52–74.

Kijne J W, Barker R and Molden D. 2003. Water productivity in agriculture: Limits and opportunities for improvement. *Comprehensive Assessment of Water Management in Agriculture Series*. CAB International, Wallingford, UK in association with International Water Management Institute (IWMI), Colombo.

Kumar R, Mishra J S and Hans H. 2018. Enhancing productivity of rice-fallows of eastern India through inclusion of pulses and oilseeds. *Indian Farming* **68**(8): 7–10.

Lal R and Miller F P. 1990. Sustainable farming for tropics. *Sustainable Agriculture: Issues and Prospective*, Vol. 1, pp. 69–89. Singh R P (Ed). Indian Society of Agronomy, IARI, New Delhi.

Ozkan B, Akcaoz H and Karadeniz F. 2004. Energy requirement and economic analysis of citrus production in Turkey. *Energy Conversion and Management* **45**: 1821–30.

Padhi A K. 1993. Productivity and economics of rice-based cropping systems. *Indian Journal of Agronomy* **38**(3): 351–56.

Paramesh V, Chakurkar E B, Bhagat T, Sreekanth G B, Kumar H B C, Rajkumar S, Gokuldas P P, Mahajan G R, Manohara K K and Ravisankar N. 2021. Impact of integrated farming system on residue recycling, nutrient budgeting and soil health. *The Indian Journal of Agricultural Sciences* **91**(1): 44–48.

Pimentel D and Burgess M. 1980. Energy inputs in corn production. *Handbook of Energy Utilization in Agriculture,* pp. 67–84. Pimentel D (Ed). CRC Press, Boca Raton, Florida.

Porpavai S, and Marimuthu R. 2018. Development of integrated farming system eastern Uttar Pradesh. *Indian Journal of Agronomy* **52**: 11–15.

Porpavai S and Marimuthu R. 2018. Development of integrated farming system model for marginal farmers of Cauvery delta zone. *Indian Journal of Ecology* **45**(1): 183–86.

Pretty J, Benton T G, Bharucha Z P, Dicks L V, Flora C B and Godfray H C. 2018. Global assessment of agricultural system redesign for sustainable intensification. *Nature Sustainability* **1**(8): 441–46.

Ram R A and Verma A K. 2015. Energy input, output and economic analysis in organic production of mango (*Mangifera indica*) cv. Dashehari. *The Indian Journal of Agricultural Sciences* **85**(6): 827–32.

Ray K, Banerjee H, Paul T and Das T K. 2016. Irrigation and sulphur fertilization effects on the productivity, profitability and greenhouse gases emissions in Indian mustard. *Experimental Agriculture* **52**(3): 434–46.

Rockstrom J and Barron J. 2007. Water productivity in rainfed systems: Overview of challenges and analysis of opportunities in water scarcity prone savannahs. *Irrigation Science* **25**: 299–311.

Salehi M, Ebrahimi R, Hassan A M and Mobtaker G. 2014. An assessment of energy modelling and input costs for greenhouse button mushroom production in Iran. *Journal of Cleaner Production* **64**: 377–83.

Shanmugam P M, Sangeetha S P, Prabu P C, Varshini S V, Renukadevi A, Ravisankar N, Parasuraman P, Parthipan T, Satheeshkumar N, Natarajan S K and Gopi M. 2024. Crop-livestock-integrated farming system: A strategy to achieve synergy between agricultural production, nutritional security and environmental sustainability. *Frontiers in Sustainable Food Systems* **8**: 1338299. doi: 10.3389/fsufs.2024.1338299

Sharma S, Rana V S, Pawar R, Lakra J and Racchapannavar V. 2021. Nano fertilizers for sustainable food production: A review. *Environmental Chemistry Letter* **19**: 1693–714.

Singh R N, Praharaj C S, Kumar R, Singh S S, Kumar N and Singh U. 2017. Influence of rice (*Oryza sativa* L.) habit groups and moisture conservation practices on soil physical and microbial properties in rice+lathyrus relay cropping system under rice fallows in Eastern Plateau of India. *The Indian Journal of Agricultural Sciences* **87**(12): 1633–39.

Singh S and Mittal J P. 1992. *Energy in Production Agriculture*, pp. 6–12. Mittal Publications, New Delhi, India.

Singh S and Toor M S. 2005. Agrarian crisis with special reference to indebtedness among Punjab farmers. *Indian Journal of Agricultural Economics* **60**(3): 335–46.

Soni P, Taewichit C and Salokhe V M. 2013. Energy consumption and CO_2 emissions in rainfed agricultural production systems of North-east Thailand. *Agricultural Systems* **116**: 25–36.

Taki M, Ajabshirchi Y, Mobtaker H G and Abdi R. 2012. Energy consumption, input-output relationship and cost analysis for greenhouse productions in Esfahan Province of Iran. *American Journal of Experimental Agriculture* **2**(3): 485–501.

Tiwari P N. 1993. Integrated farming research for sustaining food production. *Journal of Nuclear Agriculture Biology* **20**: 1–13.

Tuti M D, Vedprakash B M, Pandey R, Bhattacharyya D, Mahanta J K, Bisht M K, Mina B L, Kumar N, Bhatt J C and Srivastva A K. 2012. Energy budgeting of colocasia-based cropping systems in the Indian sub-Himalayas. *Energy* **45**: 986–93.

Wells C. 2001. *Total Energy Indicators of Agricultural Sustainability: Dairy Farming Case Study*. Technical Paper, MAF Information Bureau, Wellington, New Zealand.