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RESEARCH ARTICLE

Systemic evaluation of integrated farming in semi-arid Bundelkhand: Economic, employment and sustainability outcomes

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Abstract

This study presents a comprehensive three-year (2021–2024) evaluation of a 1.00 ha Integrated Farming System (IFS) model established at Banda University of Agriculture and Technology, Banda, with support from National Bank for Agriculture and Rural Development(NABARD). The model integrated fourteen farm-based enterprises, including cropping, vegetables, fruits, fodder, dairy, poultry, duckery, farm pond-based fishery, mushroom, honeybee, organic recycling, low-cost nursery, post-harvest processing and solar energy, to address the economic and ecological challenges of semi-arid rainfed farming systems. Component-wise analysis revealed substantial variation in profitability and economic viability among the enterprises. Fishery emerged as the most profitable enterprise, with a net return of ₹222174 and a benefit-cost ratio (BCR) of 1.70, followed by organic recycling, the cropping system and dairy units. In contrast, enterprises such as duckery, mushroom cultivation and beekeeping performed poorly due to climatic unsuitability and market-related constraints. The cumulative gross return over the three-year period was ₹2089753, with a net return of ₹525347, despite capital investments being amortized over a ten-year period. Employment generation potential was substantial, contributing to enhanced livelihood opportunities in the region. When incomefrom family labour and savings from solar electricity (₹131754) were included, the overall benefit-cost ratio improved from 0.34 to 0.69. Optimization analysis identified eight shortlisted components that exhibited superior economic performance and employment generation potential. The integrated system showed a BCR of 1.18 when livelihood contributions were included. Overall, the study underscores that strategic enterprise integration, internal input generation and diversification significantly enhance the sustainability and resilience of IFS models. It concludes that context-tailored IFS approaches can significantly improve livelihood security, farm productivity and ecological sustainability in resource-constrained dryland regions like Bundelkhand.

Keywords: bundelkhand; dryland agriculture; economic viability; employment generation; farm diversification; integrated farming system; optimization; semi-arid agroecology; sustainability

Introduction

The Bundelkhand region, spanning southern Uttar Pradesh and northern Madhya Pradesh, has long been emblematic of persistent agrarian distress typical of Indias' semi-arid zones (1). The region is marked by erratic and scanty rainfall, frequent droughts and prolonged dry spells. These climatic vulnerabilities are further exacerbated by weak irrigation infrastructure, rapidly depleting groundwater resources, degraded soil health and limited access to agricultural inputs and support services for small and marginal farmers. Under such fragile agro-ecological conditions, farming practices are predominantly limited to mono-cropping or unsynchronized double cropping, with very limited integration of livestock, negligible input recycling and minimal scope for risk mitigation (2, 3). Collectively, these conditions have contributed to declining farm productivity, deterioration of soil health and sustained rural livelihood insecurity (4).

These observations were validated by a baseline socio-economic survey conducted across six districts- Banda, Chitrakoot, Hamirpur, Jalaun, Lalitpur and Mahoba- prior to project intervention. The survey revealed that over 50 % of farmers were marginal landholders (owning less than 1 ha) and nearly 60 % had not attained education beyond class IX. Annual household incomes were generally below ₹50000 and only 20 % of respondents reported year-round access to irrigation. Livestock rearing was largely limited to indigenous cattle and buffalo, while poultry, duckery and goat farming were mostly absent. Vegetable cultivation was practiced mainly for household consumption. Despite these challenges, a significant number of farmers expressed willingness to diversify their farming systems, provided adequate public support was available. Dairy, poultry, fishery and horticulture emerged as the most preferred enterprises, indicating a latent interest towards integrated and diversified farming approaches (5).

In this context, IFS offer a promising framework for revitalizing smallholder agriculture in ecologically vulnerable areas (6–8). IFS involves the purposeful integration of multiple farm components- such as crops, livestock, horticulture, aquaculture, composting and post-harvest processing- within a single farm unit to create a resilient and self-sustaining production system. From an ecological perspective, IFS is designed to mimic natural ecosystems through closed-loop nutrient cycling, improved water conservation and the use of renewable energy sources. Economically, it allows for risk diversification, which ensures a continuous income flow across seasons and improves resource-use efficiency through on-farm recycling and value addition.

This paper is based on a three-year action research project (2021–2024), funded by the NABARD and implemented at Banda University of Agriculture and Technology, Banda (U.P.). The study was conducted on a 1.00 ha IFS model farm, initially established by the university in 2018 as a live demonstration unit aligned with the regions' agro-ecological and socio-economic realities. Building upon this foundation, the NABARD-funded research initiative aimed to scientifically evaluate and optimize the IFS model to enhance its effectiveness and scalability.

The project pursued four core objectives: First was to assess the productivity and profitability of various IFS components under real-world constraints; second, to evaluate the systems' potential for rural employment generation and livelihood support ; third, to enhance sustainability through resource recycling, solar-powered irrigation and localized postharvest value addition; and fourth, to identify and optimize the most efficient combination of IFS components using economic and resource-based simulation models for wider adaptability and replication.

By systematically documenting biophysical outputs, economic performance and farmers' perspectives, this study positions IFS merely as a technical innovation but as a comprehensive livelihood strategy. It offers grounded, system-level evidence to inform ongoing policy debates on sustainable agriculture and rural transformation in rainfed, resource-constrained regions of India.

Materials and Methods

Study area and project duration

The study was conducted at the IFS research unit located at Banda University of Agriculture and Technology, Banda, Uttar Pradesh (25° 31′27″ N, 80°20′43″ E). The site falls within the drought-prone Bundelkhand agro-climatic zone, which is characterized by erratic rainfall, saline soils with low-fertility soils and recurring dry spells. The IFS unit was initially conceptualized and partially established in 2018, with key infrastructure such as a farm pond, composting beds and initial cropping and horticultural systems.

Building upon this foundation, a three-year action research project entitled "Multi-Level Employment Generation through Integrated Farming System for Sustainable Livelihood in Bundelkhand Region" was implemented from July 1, 2021 to June 30, 2024, with financial support from the NABARD. The project aimed to refine, expand and optimize the IFS model to address the resource and livelihood constraints faced by smallholder farmers in the region.

Socio-economic context and baseline survey

To design a context-specific and farmer-centric IFS model, a baseline socio-economic survey was conducted prior to project intervention. The survey covered 270 farmers across six districts of the Bundelkhand region: Banda, Chitrakoot, Hamirpur, Jalaun, Lalitpur and Mahoba. The primary objectives were to assess prevailing farming practices and livelihood constraints and to inform the selection and design of appropriate IFS unit.

Key findings from the survey revealed that 52 % of farmers were marginal landholders (< 1 ha) and 27.6 % were small farmers owing between 1 ha and 2 ha. The average landholding size ranged from 1.38 ha in Banda to 3.46 ha in Lalitpur. Educational attainment was generally low, with around 59 % of farmers having completed education only up to class IX. Nearly 39 % of respondents reported annual household incomes in the range of ₹30000–50000, while less than 16 % earned more than ₹100000 annually, reflecting a high degree of economic vulnerability.

Irrigation access was largely seasonal, with only 20 % of farmers reporting year-round supply. Tube wells were the most common source of irrigation (53.76 %). Although water insecurity was identified as a major concern, 87 % of respondents rated the quality of irrigation water as satisfactory. Livestock ownership was moderate: 42.6 % of farmers reared *desi* buffaloes and 38 % kept indigenous cows, but over 57 % reported having no cows due to fodder shortages. Goat rearing was practiced by 30.1 % of respondents, while poultry farming was rare (0.36 %). Despite 38 % of farmers producing Farmyard manure (FYM), only 7.9 % practiced vermicomposting, largely due to inadequate awareness and lack of training.

Widespread dissatisfaction was reported with existing crop production systems, irrigation facilities, market access and income levels especially the districts of Mahoba, Lalitpur and Jalaun. More than 63 % of respondents reported that farming alone could not meet their financial and food needs. Awareness of IFS was limited, with only 45.5 % of farmers having prior knowledge of the concept; however, there was a strong inclination towards enterprise diversification. Dairy farming was preferred by 54.8 % of respondents, followed by poultry, fisheries and horticulture. Many farmers expressed readiness to invest in soil improvement and irrigation infrastructure, provided adequate support was available through government schemes.

The prevailing cropping systems were dominated by cereals, pulses and oilseeds, while fruits and vegetables were cultivated mainly for home consumption. Integrated farming practices were rare and largely confined to isolate instances of buffalo rearing and fruit orchards establishment. These insights reinforced the need for a holistic, integrated and resource-efficient farming model capable of enhancing income stability, food security and ecological sustainability in the region.

Component selection and IFS design

Based on agro-climatic suitability, resource availability and findings from the baseline survey, the 1.00 ha IFS unit was redesigned to integrate 14 complementary components (Table 1). These components included: field crops (cereals, pulses, oilseeds, green manures); fruit orchards intercropped with vegetables; fodder crops (lucern and sorghum during the first year, followed by guinea grass from the second year onwards; livestock enterprises (cows, poultry and ducks); aquaculture integrated within a rainwater-harvesting farm pond; mushroom cultivation and beekeeping units; a nursery unit, organic input production systems (vermicompost, NADEP, Indore compost, Jeewamrit and Beejamrit); solar energy systems (a 5 HP solar pump and a 1.5 kW solar power unit) and a post-harvest processing unit for vegetable pickle production.

The overall layout of the IFS model (Fig. 1) was designed to ensure year-round productivity, optimise spatial efficiency and promote closed-loop nutrient recycling within the farming system.

Infrastructure development

A farm pond measuring 40 m × 32 m × 3 m was constructed to harvest surface runoff from a 5 ha catchment area. The pond served a dual purpose, supporting both fish rearing and supplemental irrigation. Supporting infrastructure included sheds for cows and poultry, a duck shelter constructed using bamboo and locally available materials and composting facilities comprising 2 NADEP units, 1 Indore compost unit and 4 vermicompost beds. A 5 HP solar powered irrigation pump and a 1.5 kW solar electricity system were installed to meet irrigation and lighting requirements. In additional, a vegetable pickle-making unit was developed with an initial capacity of 100 kg/day, later expanded to 200 kg/day.

Cropping and horticulture

The cultivated land was divided into four main blocks as follows:

Block 1 (0.20 ha): Moong- Wheat- Urdbean rotation

Block 2 (0.20 ha): Groundnut- Mustard- Lobia rotation

Block 3 (0.25 ha): Fruit trees (lemon, kinnow, banana, papaya and custard apple) intercropped with seasonal vegetables

Block 4 (0.15 ha): Fodder crops (lucerne, MP chari and guinea grass)

Climbing vegetables such as ridge gourd, bottle gourd and sponge gourd were trained along wire fencing while *Karonda* was planted along the remaining farm boundary to enhance fencing diversification.

Livestock and fishery integration

The livestock component initially consisted of three cows (two crossbred and one indigenous). However, following outbreaks of lumpy skin disease, the unit shifted to indigenous cattle breeds. Poultry was reared in 3 annuals cycles- CARI Priya (2021- 22), CARI Devendra (2022- 23) and Kadaknath (2023-24), with 100 birds maintained per batch. A duckery unit comprising 25 khaki campbell ducks was also maintained on a similar rotational basis. Fish culture was practiced annually with the stocking of 3000 fingerlings of mixed species, including rohu, katla, mrigal, common carp and grass Carp. Fish were fed using on-farm grain by-products and oilcakes to minimise external feed inputs.

Organic input production

Organic input production included four vermicompost beds with a total capacity of 1300 kg, 2 NADEP compost units (5000 kg capacity) and one Indore bed (2200 kg capacity). Additionally, 4 barrels with a combined capacity of 800 L were used for the preparation of jeewamrit and beejamrit. These organic inputs applied across all cropping and horticultural components to minimize external input dependency and enhance soil fertility.

Postharvest and renewable energy use

A small-scale processing unit was used to convert surplus vegetables into pickles. A grain mill was employed to process farm-grown cereals into feed for cows, poultry and fish. Solar energy systems supported irrigation and operational electricity requirements, thereby reducing both the carbon footprint and recurring energy costs of the farming system.

Data collection and analytical framework

Data were collected on component-wise productivity, resource utilisation, input-output economics, soil fertility parameters, energy consumption and livestock and fishery performance. Soil and water quality assessments were conducted in May 2019 and June 2024. Soil parameters analysed included pH, Electrical Conductivity (EC),

Table 1. Components of IFS model with specifications (Total area: 1.00 ha)

SN	Component included as the intervention	Area/ Size
1.	Farm pond and fishery along with vegetable and fruit cultivation along the pond borders and pathways	0.15 ha
2.	Cropping system	0.40 ha
3.	Vegetable cultivation as intercropping in fruit orchard	0.25 ha
4.	Fruit crops with intercropping of vegetable crops	
5.	Poultry unit	100 birds
6.	Duck unit	25 birds
7.	Cow	3 nos.
8.	Fodder cultivation	0.15 ha
9.	Honeybee	10 boxes
10.	Mushroom unit	2 racks
11.	Nursery	
	Low-tunnel shed-net nursery beds (20 ft x 3.5 ft x 3 ft)	2 nos.
	Low-cost temporary nursery (15 ft x 10 ft x 6 ft)	1
12.	Organic recycling	
	Vermicompost beds (1300 kg production capacity)	04
	NADEP compost beds (5000 kg production capacity)	02
	Indore composting bed (2200 kg production capacity)	1
	Natural farming formulations production (Jeewamrit & beejamrit) (800 lit. production capacity)	4 barrels
13.	Solar energy unit	
	Solar irrigation water pump	5 hp
	Solar electricity unit	1.5 kW
14.	Post-harvest technology unit (Capacity of production unit was extended to 200 kg from year 2022-23)	100 kg
	Area allotted for farm structures	0.05 ha

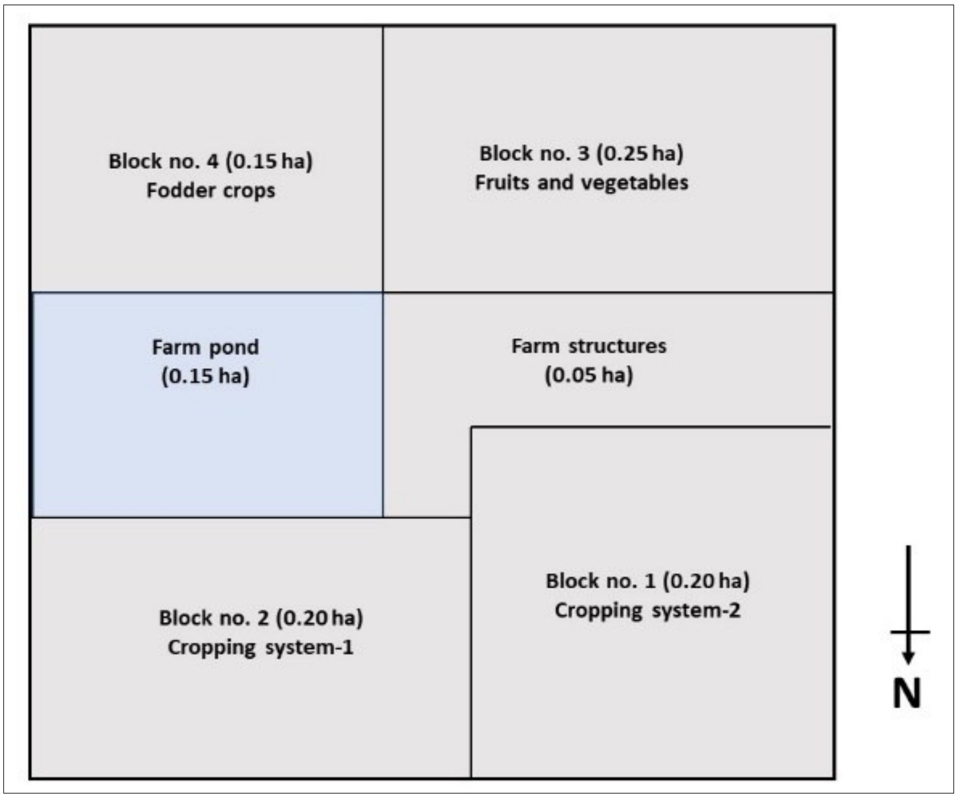

Fig. 1. Layout of IFS unit.

bulk density, organic carbon, available nitrogen, phosphorus and potassium (NPK) and dehydrogenase activity. Tube well water samples were analyzed for Total Dissolved Solids (TDS).

Optimization framework

To evaluate the most efficient mix of enterprises, a Linear Programming (LP) model was developed using Python (version 3.10, 2024) with the PuLP and SciPy libraries (9) and executed in a Jupyter Notebook environment under Windows 11. Decision variables represented the area or scale allocated to each enterprise, subject to constraints related to total land availability (1 ha), available capital and family labour. The objective function was designed to maximize Net Monetary Return (NMR) and BCR, based on empirical data recorded during 2021–2024. The model was solved using the CBC (Coin-or Branch and Cut) solver integrated within the PuLP framework. All input coefficients and constraints were derived from observed field data to ensure realism. The optimization process emphasized internal resource recycling, enterprise complementarities and ecological linkages within the integrated farming system.

Results and Discussion

Component-wise economic performance

The economics performance of the IFS unit was evaluated over a three-year period (2021–2024) by assessing the productivity, Cost of Production (COP), Gross Monetary Return (GMR), Net Monetary Return (NMR) and BCR. The cropping system, implemented on 0.40 ha, followed two rotations: moong- wheat- urdbean and groundnut - mustard- lobia- with dhaincha as a summer green manure. Over the three-year period, the system produced 128.95 quintals in Rice Equivalent Yield (REY), resulting in a NMR of ₹141009 and a BCR of 0.91, indicating moderate profitability.

Vegetables were grown as intercrops within the orchard and along the pond embankments and field boundaries. This unit produced 138.93 quintals in REY, yielding a NMR of ₹130666 and a BCR of 0.69, making it one of the stronger income-generating units. The fruit component, primarily banana, citrus, custard apple and papaya, yielded a total production of 1946 kg. With minimal input costs of ₹15568, this unit generated a modest NMR of ₹16732 and a BCR of 1.07, suggesting its potential long-term economic viability.

The fodder unit, implemented on 0.15 ha, produced 446.5 quintals of green fodder to support livestock. Although primarily a supportive component, it generated a NMR of ₹31355 with a BCR of 0.58. The cow unit, managed with three indigenous cows, produced 8916 L of milk and 32133 kg of dung over the study period. This component emerged as a key component, yielding a NMR of ₹173768 and a BCR of 0.67, largely due to its dual role in income generation and internal nutrient recycling. Among other components, the poultry unit (100 birds/year) recorded a modest NMR of ₹19549 with a low BCR of 0.10. The duckery unit faced market-related constraints and low productivity, leading to a net loss of ₹26270 and a BCR of 0.01. In contrast, the fishery unit, integrated within a 0.15 ha farm pond, emerged as the most profitable enterprise, generating 3209 kg of fish with a NMR of ₹222174 and a BCR of 1.70. The mushroom and honeybee units were economically unviable, recording negative returns with BCR values of -0.24 and -0.78 respectively. The nursery unit produced 13250 seedlings and generated a net return of ₹9875 with a BCR of 0.59, indicating scope for future potential.

The organic recycling unit, which produced 53850 kg or L of compost and natural liquid inputs, contributed significantly to ecological sustainability while generating an NMR of ₹55686 and a BCR of 1.06. The postharvest processing unit, primarily engaged in mixed pickle production, demonstrated limited profitability, generating a NMR of ₹8880 with a BCR of 0.17. Detailed figures for all components are presented in Table 2.

Table 2. Component-wise production and economic performance of the IFS Unit (2021–2024)

Component	Area/Size	Production	COP (₹)	GMR (₹)	NMR (₹)	BCR
Cropping System	0.40 ha	128.95 quintals of Rice Equivalent Yield (REY)*	155,592	296,601	141,009	0.91
Vegetables	0.25 ha as intercropping in fruit crops and at the pond and field borders	138.93 quintals of REY#	188,867	319,533	130,666	0.69
Fruit Crops	0.25 ha	1,946 kg	15,568	32,300	16,732	1.07
Fodder	0.15 ha	446.5 quintals	53,995	85,350	31,355	0.58
Cow Unit	3 cows	8,916 L milk, 32,133 kg dung	259,585	433,353	173,768	0.67
Poultry	100 birds/year	6,139 eggs, 935.8 kg meat, 2,882 kg manure	193,453	213,002	19,549	0.10
Duckery	25 ducks	44 eggs	26,490	220	−26,270	0.01
Fishery	0.15 ha pond	3,209 kg	130,816	352,990	222,174	1.70
Mushroom	2 racks	54 kg	5,712	4,320	−1,392	−0.24
Honeybee	10 boxes	6.1 kg honey	8,306	1,830	−6,476	−0.78
Nursery	3 beds	13,250 seedlings	16,625	26,500	9,875	0.59
Organic Recycling	4 beds of vermicompost, 1 bed each of Indore and NADEP compost, periodic	53,850 kg or litres (compost & natural inputs)	52,314	108,000	55,686	1.06
Post-harvest Processing	Initial capacity 100 kg, which was extended to 200 kg from second year	500 kg pickle	51,120	60,000	8,880	0.17

Note:

* Two different cropping systems in each block of 0.20 ha were adopted, viz. Moong-Wheat-Urdbean and Groundnut-Mustard-Lobia, with *Dhaincha* as alternate summer seasons for green manuring. Yield of different crops (including dry matter added by *Dhaincha*) is converted into Rice Equivalent Yield (REY).

#Similarly various crops are grown as intercropping in fruit crops and at the pond and field borders. Therefore, REY is considered here for analysing economics of vegetable crops.

Overall economic performance of the IFS unit

Over the three-year period, the cumulative assessment included both recurring and capital costs. Infrastructure investments such as sheds, pond and solar systems amounted to ₹1322710, with an annualised capital allocation of ₹132271, assuming a 10-year useful lifespan. The solar irrigation pump and domestic solar unit together resulted in electricity savings of 18822 kWh, equivalent to ₹131754 over the 3-year period.

During 2021–22, the total costs (recurring plus capital) was ₹551025, with a GMR of ₹637318 and solar energy savings of ₹43918. This resulted in a NMR of ₹130211 and a BCR of 0.24. In 2022–23, better integration among system components led to reduced costs and improved outcomes, with a total return of ₹687896, a NMR of ₹174278 and a BCR of 0.34. In 2023–24, optimal synergies among components led to the highest NMR of ₹220858 and the best BCR of 0.44.

Over three years, the total investment amounted to ₹1564406, while the cumulative gross return was ₹2089753. This resulted in an overall NMR of ₹525347 and an average BCR of 0.34, as shown in Table 3.

Employment generation potential

Labour constituted a major share of the recurring costs in the IFS, indicating its strong potential for on-farm employment generation. The system generated a total of 2392 workdays over the 3-year study period, corresponding to an average of 2.18 labour units per day (Table 4). The valuation of labour was considered at ₹230 per day, representing the imputed economic contribution of family labour rather than hired wage payments. The distribution of labour across enterprises varied considerably. Vegetable cultivation (507 workdays), the cattle unit (460 workdays) and the cropping system (448 workdays) were the most labour-intensive components, together accounting for nearly 60 % of the total workdays generated under the IFS model.

Table 4. Component-wise employment generation in IFS (workdays)

SN	Component	2021–22	2022–23	2023–24	Total
1	Cropping system	130	151	167	448
2	Vegetables	142	177	188	507
3	Fruit crops	31	23	25	79
4	Fodder	52	44	39	135
5	Cow	167	139	154	460
6	Poultry	81	92	78	251
7	Duck	5	4	0	9
8	Fishery	48	78	81	207
9	Mushroom	4	2	0	6
10	Honeybee	8	2	0	10
11	Nursery	19	11	14	44
12	Postharvest processing	27	35	38	100
13	Organic recycling	51	41	44	136
14	Solar pump & electricity system	0	0	0	0
	Total workdays	765	799	828	2,392
	Avg. per day employment (units)	2.10	2.19	2.27	2.18

Table 3. Overall economics of the IFS Unit (2021–2024) including solar system

Year	Recurring costs (₹)	Permanent costs (₹)	Total cost (₹)	GMR from IFS (₹)	Value of electricity saved (₹)	GMR incl. electricity (₹)	Net return (₹)	BCR
2021-22	418,754	132,271	551,025	637,318	43,918	681,236	130,211	0.24
2022-23	381,347	132,271	513,618	643,978	43,918	687,896	174,278	0.34
2023-24	367,492	132,271	499,763	676,703	43,918	720,621	220,858	0.44
Total	1,167,593	396,813	1,564,406	1,957,999	131,754	2,089,753	525,347	0.34

Note: In this study, all permanent infrastructure investments (such as livestock sheds, composting beds, nursery units, post-harvest units and the solar energy system, etc.) were considered under capital costs. To account for their long-term utility, these costs were amortized over a standard operational lifespan of 10 years. Accordingly, one-tenth of the total permanent cost was allocated annuallyf and this share was added to the yearly economic assessment.

Other components, such as fishery (207 workdays), organic recycling (136 workdays) and fodder production (135 workdays), provided moderate labour engagement, mainly during specific management operations like feeding, compost turning and fodder harvesting. In contrast, duckery (9 workdays), mushroom (6 workdays) and honeybee units (10 workdays) required minimal labour requirements, reflecting their small operational scale and short activity duration. This component-wise labour distribution illustrates that the IFS model offers diversified employment opportunities across enterprises and seasons, ensuring more uniform utilization of family labour and reducing idle periods commonly observed in rainfed farming systems.

Year-wise employment generation

Year-wise analysis showed a steady increase in total labour engagement, from 765 workdays in 2021–22 to 828 workdays in 2023–24 (Table 5). The corresponding value of labour increased from ₹175950 in the first year to ₹190440 in the third year, amounting to a cumulative income of ₹550160. The consistent increase in both workdays and labour value reflects the gradual stabilization of the IFS model and improved coordination and integration among its component enterprises.

The results clearly indicate that as the system matures, inter-enterprise linkages strengthen, generating more regular employment opportunities. Hence, the IFS model not only enhances resource use efficiency but also provides a sustainable means of livelihood support, particularly relevant for addressing underemployment and seasonal migration in semi-arid regions like Bundelkhand.

Economic contribution of labour and solar energy

The annual imputed labour incomes were ₹175950 in 2021–22, ₹183770 in 2022–23 and ₹190440 in 2023–24. When recalculating NMR by adding the economic value of family labour and savings from solar energy utilisation, the BCRs increased to 0.56, 0.70 and 0.82 respectively. Cumulatively, the integrated NMR was ₹1075507 and the average BCR increased to 0.69 (Table 6), reflecting the socio-economic sustainability of the IFS model.

Optimization of components within the IFS unit

The optimization analysis identified eight components as the most viable enterprises based on profit-to-cost efficiency, system synergy and practicality in the Bundelkhand agro-ecological context. These components included fishery, organic recycling, cropping system, cattle unit, vegetables, fodder, nursery and fruit orchard. Their average three-year economics are presented in Table 7.

Conversely, components such as poultry, duckery, mushroom, honeybee and post-harvest processing were excluded from the optimized model due to low or negative economics returns, poor market linkage and management-related inconvenience.

Economics of optimized IFS

When only the eight most economically efficient components were considered, the cumulative recurring cost over the three-year period amounted to ₹882512, while the apportioned capital cost was ₹90255. The combined GMR was ₹1654627 and the NMR was ₹681860, yielding in a BCR of 0.70 (Table 8).

Employment-linked economics of optimized IFS

These 8 components together generated 2016 workdays over the 3-year period, translating into an imputed family labour income ₹463680. When this labour income was added to the NMR derived from farm activities, the total integrated return increased to ₹1145540, with a corresponding BCR of 1.18 (Table 9). This finding confirms that the optimized IFS model not only ensures economic profitability but also supports sustainable employment generation and diversified income streams, particularly in resource-constrained semi-arid regions like Bundelkhand.

The component-wise analysis of the IFS model revealed substantial differences in profitability across enterprises, influenced by agro-ecological feasibility, management intensity and internal system synergies. The cropping system, which achieved 128.95 quintals of rice equivalent yield with a BCR of 0.91, demonstrated consistent returns owing to its diversified rotation of pulses, oilseeds and cereals, along with the incorporation of green manure (Dhaincha). These practices are aligned with sustainable dryland strategies advocated in similar agroecosystems (10, 11).

Vegetable cultivation, practiced along field bunds and as intercrops within orchard systems, generated a net return of ₹130666 and contributed effectively to income diversification despite a moderate BCR of 0.69. Its profitability stemmed from short cycles, local market linkage and high consumer demand validating

Table 5. Year-wise employment generation in IFS

Year	Labour workdays utilized	Labour cost (₹)	Per day employment (units)
2021–22	765	175,950	2.10
2022–23	799	183,770	2.19
2023–24	828	190,440	2.27
Total	2,392	550,160	2.18 (avg.)

Table 6. IFS economics considering family labour and electricity savings

Year	Total cost (recurring + permanent) (₹)	NMR including family labour & solar benefit (₹)	Benefit-cost ratio (BCR)
2021-22	551,025	306,161	0.56
2022-23	513,618	358,048	0.70
2023-24	499,763	411,298	0.82
Total	1,564,406	1,075,507	0.69

Table 7. Three years average economics of best eight components found from the optimization process, within the whole IFS unit

SN	Component	Avg COC (Rs.)	Avg GMR (Rs.)	Avg NMR (Rs.)	Avg BCR
1	Farm pond and fishery	43,605	117,330	74,057	1.75
2	Organic recycling	17,438	36,000	18,562	1.07
3	Cropping system	51,864	98,867	47,003	0.91
4	Cattle unit	86,528	144,451	57,923	0.74
5	Vegetable cultivation	62,956	106,177	43,222	0.72
6	Fodder production	18,066	28,450	10,384	0.62
7	Nursery	5,542	8,833	3,292	0.60
8	Fruit orchard	8,239	10,767	2,527	0.33

Table 8. Component-wise economics of optimized IFS including eight best performing enterprises (three years total values are used)

a	b	c	d	e	f	g	h
Component	**Total establishment cost**	**Three years share of establishment cost among the ten years (b / 10 x 3)**	**Recurring costs**	**Total COP (c + d)**	**GMR**	**NMR (f – e)**	**BCR (g / e)**
Farm pond and fishery	134000	40200	130816	171016	352990	181,974	1.06
Organic recycling (NADEP, Vermicompost, Indore compost, Natural farming formulation)	37650	11295	52314	63609	108000	44,391	0.70
Cropping system	0	0	155592	155592	296601	141009	0.91
Cattle unit	114000	34200	259585	293785	433353	139568	0.48
Vegetable cultivation	0	0	188867	188867	319533	130666	0.69
Fodder production	0	0	53995	53995	85350	31355	0.58
Nursery	15200	4560	16625	21185	26500	5315	0.25
Fruit orchard	0	0	24718	24718	32300	7582	0.31
Total	300850	90255	882512	972767	1654627	681860	0.70

Table 9: Three-Year economics of optimized IFS including family labour income

SN	Particulars	Value (₹)
1	Permanent cost (3-year share @ ₹30085/year)	90255
2	Recurring/consumable costs	882512
3	Total cost (1 + 2)	972767
4	Net return from farm produce	681860
5	Family labour workdays (3 years)	2016
6	Income from family labour (2016 × ₹230)	463680
7	Total NMR incl. family labour (4 + 6)	1145540
8	Benefit-Cost Ratio (7 ÷ 3)	1.18

findings from horticulture-intensive IFS models (12, 13). The organic recycling unit proved efficient (BCR 1.06), utilizing NADEP, vermicompost and jeevamrit to generate internal inputs, thereby reducing dependence on external fertilizers and improving soil structure. This aligns with agroecological approaches that stress closed-loop nutrient cycling (14, 15).

The fishery component emerged as the most lucrative enterprise (NMR ₹222174; BCR 1.70). Its success was attributed to efficient water-use synergy, low maintenance costs and regular harvest cycles- consistent with studies highlighting the productivity-enhancing role of farm ponds in semi-arid regions (16, 17). In contrast, enterprises such as duckery, mushroom, honeybee and post-harvest units showed negative or marginal returns due to climatic unsuitability, scale constraints or poor market access. These challenges echo findings from low-input IFS research which caution against indiscriminate replication of enterprise models without adequate local contextualization (18–20).

The IFS unit demonstrated steady improvement in profitability, with the BCR increasing from 0.24 in the first year to 0.44 by the third year. The cumulative GMR, including solar savings (₹2089759), surpassed the total cost of ₹1564406. This trajectory confirms that once established, integrated systems benefit from cost reduction, internal input generation and operational synergies. These outcomes are consistent with long-term studies indicating that IFS models typically require 2–3 years for stabilization before they reach peak performance (21, 22). Reduced operational costs in later years suggest enhanced learning, integration and reuse efficiencies, supporting the scalability of IFS in resource-constrained regions (21, 23, 24).

The IFS model created 2392 labour workdays over three years, translating into an average of 2.18 labour units per day. This high labour absorption capacity is significant for regions like Bundelkhand, where seasonal unemployment and migration are pressing concerns (25). Vegetable cultivation, crop production and livestock rearing emerged as the most labour-intensive components, facilitating year-round engagement (26, 27). Ancillary activities such as nursery management and compost production further diversified employment opportunities across gender and skill profiles. When the economic value of family labour and solar savings were incorporated, the BCR of the full IFS model increased from 0.34 to 0.69, while that of the optimized model rose to 1.18. This integrated economic assessment presents a more realistic depiction of farm-level viability, particularly in smallholder contexts where family labour is a key resource.

The optimization process identified eight economically efficient and contextually feasible components: fishery, cropping, organic recycling, cattle, vegetables, fodder, nursery and fruit orchard. Together, these components achieved a cumulative NMR of ₹681860 with a BCR of 0.70. This finding reinforces the idea that strategic integration- rather than excessive diversification- drives the success of complex farming systems (21, 27). Livestock-based components, particularly indigenous cows (Kenkatha) paired with guinea grass fodder, contributed to nutrient cycling, manure production and household resilience. Although less profitable in isolation, these components provided significant ecological and socio-cultural value, aligning with climate-resilient agriculture frameworks (7, 28). Components such as poultry and duckery underperformed primarily due to high mortality, limited markets and management complexity. Their exclusion from the optimized model emphasizes the importance of region-specific enterprise selection rather than generic IFS replication.

The integration of solar energy systems, comprising a 5 HP irrigation pump and a 1.5 kW domestic unit- led to savings of ₹131754 over three years. Although the high initial capital cost (₹400000) limited its inclusion in the optimization model, solar integration enhanced energy autonomy, reduced operating costs and increased the climate resilience of the IFS unit. These findings support earlier research highlighting the role of renewable energy in sustainable farming transitions (29–31). With proper support under schemes like PM-KUSUM, solar integration can further improve the feasibility of IFS models in water-scarce and energy-deficient rural landscapes.

In summary, the study confirms that a well-designed, context-sensitive IFS model can enhance profitability, resource-use efficiency and employment generation while strengthening ecological resilience. When combined with renewable energy integration and optimized for local conditions, IFS offers a viable strategy for sustainable agricultural development in dryland regions such as Bundelkhand.

Conclusion

The IFS model implemented in the semi-arid Bundelkhand region demonstrated that context-specific and strategically diversified farming system can significantly enhance livelihood security, resource-use efficiency and system resilience for smallholder farmers. Over the three-year evaluation period, the IFS unit achieved notable improvements in economic returns, employment generation and internal resource cycling despite initial capital investment constraints. Component-wise analysis revealed that enterprises such as fishery, organic recycling, crop cultivation and livestock emerged as the most profitable and synergistic, whereas others such as duckery, mushroom and honeybee units were economically non-viable under existing local conditions. The optimization analysis confirmed that targeted integration, rather than indiscriminate diversification, is essential to maximizing the benefits of IFS in resource-constrained environments.

The inclusion of solar-based irrigation and domestic energy systems reduced recurring costs and improved environmental sustainability-an important step toward climate-resilient farming. Accounting for the economic value of family labour and electricity savings provided a more realistic and equitable measure of system viability, especially for marginal farmers. The systems' ability to generate over 2000 workdays across enterprises highlights its potential to reduce rural underemployment and curb distress migration.

Overall, the study supports IFS as a viable, scalable and adaptive strategy for sustainable dryland agriculture. Policy support should prioritize (i) capacity building and technical training for integrated enterprise management, (ii) linking smallholders to credit and marketing facilities, (iii) integrating renewable energy components under schemes such as PM-KUSUM and (iv) convergence of IFS with watershed and rural livelihood missions (e.g. NRLM, MGNREGS). For farmers, adoption advisories should focus on enterprise selection suited to local resource bases, promoting organic recycling, on-farm energy generation and water-use efficiency to strengthen long-term sustainability.

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Authors' contributions

AK[1] carried out the conceptualization, methodology design, field implementation, data curation, formal analysis, original draft writing and visualization. AK[2] provided supervision, validation, project administration and contributed to review and editing. NS participated in methodology development, field investigation, data collection, resource coordination and manuscript review. DS contributed to field investigation, data collection and agronomic monitoring and participated in review and editing. GSP offered supervision, technical guidance, institutional coordination and critical review. AKC conducted soil sampling and analysis, advised on nutrient management and contributed to manuscript review. YG performed the economic analysis, cost–benefit calculations, optimization modelling and created visualizations. CT integrated the agroforestry component, monitored tree–crop interactions and supported review. HM designed and assessed post-harvest components, performed value addition analysis and contributed to data analysis. AS managed vegetable systems, designed intercropping strategies and monitored field performance. MKS designed nursery and vegetable components and managed seedling production. SS developed extension linkages, coordinated community engagement, designed the farmer survey and facilitated knowledge dissemination. All authors read and approved the final manuscript. [AK[1]stands for Aniket Kalhapure and AK[2] stands for Arun Kumar].

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

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