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Suitable Integrated Farming System Models in Terms of Energetics, Greenhouse Gas Emissions and Employment Generation for the Small and Marginal Farmers

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Abstract: Food grain production has multiplied over the last two decades in India, but natural resources are overexploited in modern farming. Farmers, especially those with small and marginal holdings, are suffering losses more often than not, the cost of production is increasing year after year, and profits are not up to the necessary levels. To address such challenges, there has been a broad recognition of the importance of employing farming system approaches in research. The cultivation of cropping systems with orchard crops and livestock components can play a significant role in the optimal utilization of resources, enhancing energy use efficiency as well as the eco-efficiency index, and reducing carbon footprints. This study was carried out to create a suitable IFS model with high economic and energy efficiency for small-holder farmers in India's southern plateau and hills with a negligible impact on the environment. The following were the seven models: M_1: Rice − Groundnut; M_2: Rice − Groundnut, Pigeonpea + Sweetcorn (1:3) − Bajra, Bt cotton + Greengram (1:2) − Maize; M_3: Rice − Groundnut, Pigeonpea + Sweetcorn (1:3) − Bajra, Pigeonpea + Maize (1:3) − Sunhemp; Napier grass, Sheep (5 + 1); M_4: Rice − Groundnut, Pigeonpea + Sweetcorn (1:3) − Bajra, Bt cotton + Greengram (1:2) − Maize, Pigeonpea + Maize (1:3) − Sunhemp, Poultry unit; M_5: Guava, Hedge Lucerne, Napier grass, Bt cotton + Greengram (1:2) − Maize, Sheep (5 + 1); M_6: Guava, Bt cotton + Greengram (1:2) − Maize, Rice − Groundnut, Poultry; M_7: Rice − Groundnut, Pigeonpea + Sweetcorn (1:3) − Bajra, Pigeonpea + Maize (1:3) − Sunhemp; Napier grass, Hedge lucerne, Poultry (100), Sheep (5 + 1). Model M_1 was used to represent the local region, and the other models were compared in terms of economics, energetics, greenhouse gas emissions, and employment creation. The M_7 and M_3 models, according to the results, have higher economic efficiency (₹342.3 day^{-1}, ₹263.7 day^{-1}), increase output energy (228,529 and 183,231 MJ) net energy (258,184 and 198,920 MJ), produce net negative emissions (−2842 and −2399 kg CO_2 eq.), and create jobs year-round (112.5 and 110.5 man days year^{-1}), respectively. This is primarily because they have multiple highly efficient components that make them viable for Telangana's small and marginal farmers.

Keywords: energetics; eco-efficiency index; greenhouse gas emissions; employment generation; integrated farming system; Telangana

1. Introduction

In India, more than 85% of farming families hold around 1 ha, and the per capita cultivable land availability is 1000 sq mt [1]. The population is increasing steadily and is expected to reach 1.64 billion by 2050 [2], with the same declining land and water resources. Farmers cannot entirely depend on cropping components as they do not guarantee income every year, especially in this era of climate change. The Indian farmers, especially the small and the marginal, are concentrating more on cereal-based crop production, which is at high risk of climate anomalies, such as floods and droughts. Marginal and small farmers in general, are literally illiterate and financially handicapped. Their holdings are small and scattered and are not suited for high-tech agricultural machinery, and they work in resource poor and risk-prone diverse conditions. Also, small farmers can not afford to invest in their farms from their own savings, which reduces their chances of transforming from traditional agriculture into scientific farming. They can receive income throughout the year and enhance their standard of living through efficient management of the inputs available on the farm and the integration of multiple enterprises, which can reduce the cost of cultivation [3]. Food grain production has multiplied many times because of the green revolution, which fed the ever-growing population of India [4], but some faulty management practices in modern farming have led to the overuse of natural resources, and as a result, the sustainability of agricultural production is in jeopardy [5]. In the last two decades, farmer suicides have been at their peak because of an increase in input prices, excessive usage of inputs, price fluctuations, and weather abnormalities [6].

The continuous cultivation of crops with inorganic fertilizers, excluding the addition of manures, has led to significant concerns regarding the decline in organic carbon, essential plant macro- and micronutrients, and the depletion of soil plankton. Monocropping practices have resulted in soil fertility depletion and groundwater loss and have significantly contributed to soil erosion [7]. Farmers are also suffering with low returns and higher costs of inputs along with low opportunities for rural labor. To address these issues, it is imperative to promote crop diversification, as it not only fulfills the need for food but also provides fiber, fuel, and fodder, thereby restoring the environmental balance.

Many attempts have been made to improve the productivity of the various farming system components, but there has not been success in integrating them using the farming system approach. The integrated farming system (IFS) deserves attention in order to meet the basic needs of households, which include providing food (cereal, pulses, oilseeds, milk, fruit, honey, fish meat, etc.) for humans, animal feed and fodder, and fuel and fiber for general use. In addition to improving the economic and nutritional standing of farming families, the IFS is one of the best ways to secure sustainable livelihoods for smallholders. It can also boost employment prospects and make the most use of agricultural resources.

With the introduction of IFS models, we now have a foundation for a different kind of developmental model that aims to make small-scale farming enterprises more viable than bigger ones. Using a systematic approach to resource management, integrated farming aims to maximize a system's effectiveness. Compared to conventional farming practices, integrated farms have a much lower energy consumption since they rely less on mechanization and encourage the use of internal resources instead of external inputs like fertilizers [8]. The consumption of energy is controlled within the farm system by means of the integration of multiple affiliated farm companies. IFS models with multiple enterprises record higher net energy gain and energy productivity compared to conventional systems, which are attributed to the significantly elevated levels of output energy, farm productivity, and economic returns observed in these models [9].

The global farming scenario has been drastically changed by deforestation, urbanization, and agricultural development; this has led to resource degradation and an increase in soil carbon emissions [10]. Increased greenhouse gas concentrations in the atmosphere can also be significantly caused by unscientific forestry, agricultural, and/or other land use practices. Their combined contribution to anthropogenic greenhouse gas emissions is estimated to be approximately 22% [11]. Addressing climate change demands the adoption of sustainable agricultural practices, and IFS models stand out as one of the most effective methods to sustainably mitigate greenhouse gas emissions. Unemployment remains a significant concern in India, especially among the rural youth, and there is a possibility that it may escalate in the near future. By creating site-specific models, since IFS models generate year-round work opportunities, this dilemma may be resolved. Patel et al. [12] predicted that IFS models create more employment throughout the year as compared to existing farmer practices, which is attributed to the integration of multiple enterprises, especially livestock, which needs labor all year.

Compared to rice cropping patterns prevalent among India's small and marginal farmers, the development of a suitable Integrated Farming System (IFS) model by incorporating two or three components may enhance yields, income, soil sustainability, and employment opportunities.

The goal of this study was to create an IFS model for small-holder farmers in India's southern plateau and hills that would increase economic and energy efficiency, create jobs, and have a negligible impact on the environment.

2. Materials and Methods

2.1. Situation

A field experiment was carried out in 2021–2022 and 2022–2023 at the College of Agriculture, PJTSAU, Rajendranagar, with the goal of creating climate smart farming system models in Telangana's irrigated conditions with appropriate crop and animal components. The experimental location was located in the Southern Telangana Zone (STZ), India, at a height of 527 m above Mean Sea Level (MSL) at 17°32′10.45″ N latitude and 78°41′02.77″ E longitude (Figure 1).

Figure 1. Location of the experimental site [13].

2.2. The Climate

The meteorological data collected during the experiment's crop growth period came from the Agro Climatic Research Centre's (ACRC) meteorological observatory, which is located at the Agricultural Research Institute in Rajendranagar, Hyderabad. This meteorological observatory is 1.5 km from the experimental site. The weekly temperatures throughout the 2021–2022 study period varied from 9.60 °C to 39.2 °C at the highest point, with corresponding averages of 20.5 °C and 32.0 °C. The mean weekly relative humidity varied from 24.7% to 88.9% with an average of 56.3% in the evening and from 67% to 98.9% in the morning, with an average of 88.1%. The average weekly sunlight hours were 6.3, with a range of 1.4 to 10. With 15 wet days, the average yearly rainfall was 859.6 mm, whereas the total amount of evaporation was 246.3 mm (Figure 2).

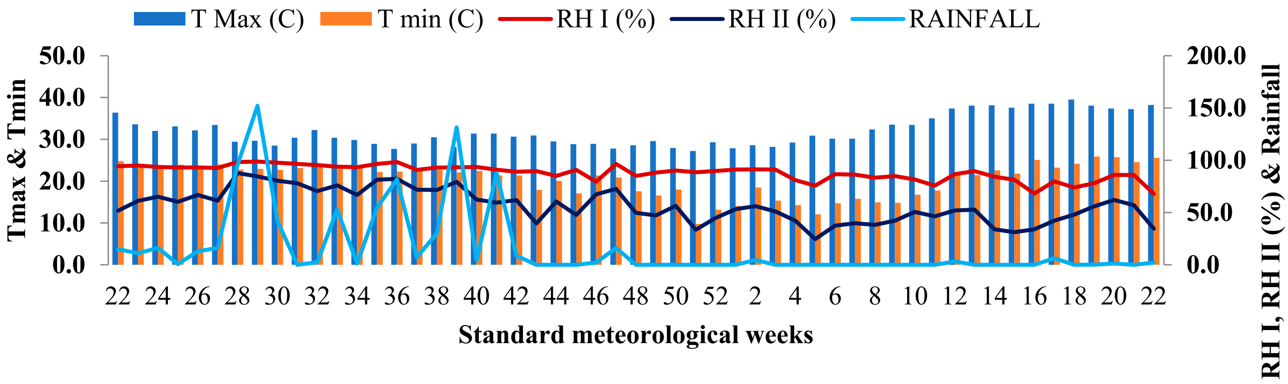

Figure 2. Weekly meteorological data for Rajendranagar, Telangana, over the 2021–2022 period [14].

The average weekly temperatures throughout the 2022–2023 study period were 19.8 °C and 31.9 °C, respectively, with a minimum of 11.2 °C and a maximum of 39.2 °C. The relative humidity ranged from 63.1 to 94.7%, with an average of 84.9%, and from 17.4% to 91.0%, with an average of 48.7%, for the morning and evening hours on a weekly basis. The mean weekly sunshine hours ranged from 0.3 to 11.0, with an average of 6.7. The average annual rainfall, distributed over 67 wet days, was 1174.4 mm, while the total amount of evaporation measured was 232.1 mm (Figure 3).

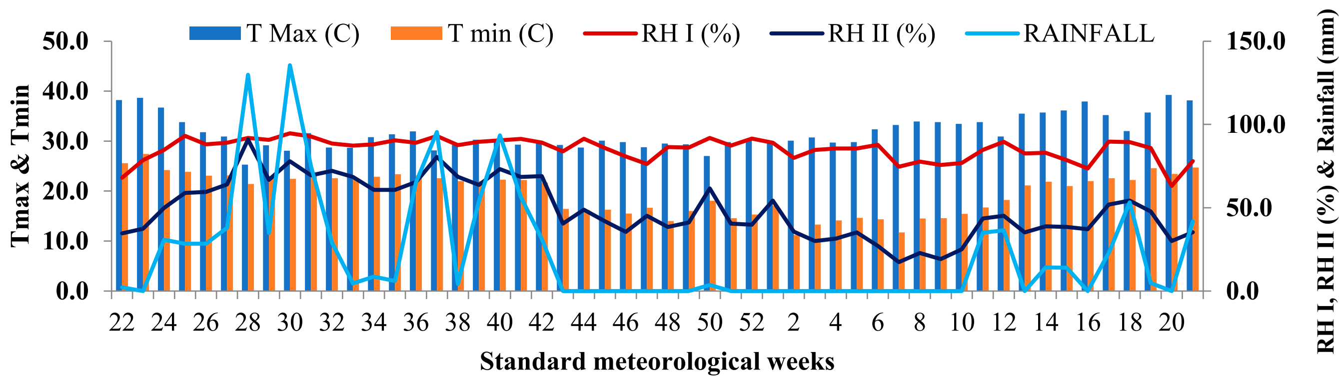

Figure 3. Details of standard week-wise meteorological data at Rajendranagar, Telangana during 2022–2023 [14].

2.3. Experiment Details

There are various components to this experiment, including farming methods, guava orchards, fodder crops, sheep, and poultry. Seven farm models or treatments were developed; of these, six (M_2, M_3, M_4, M_5, M_6, and M_7) were compared with the rice-groundnut system (M_1), a prominent farming method in Telangana, India, whereby the various components—fruit crops, fodder crops, and livestock components—are combined in varying proportions (Table 1). The farming system should have cereals, pulses, oilseeds and fodder crops along with livestock, which suits the idea of crop diversification, which is why various cropping systems are included in the following models. Cropping systems are identified based on the weather conditions, soil type and feasibility of inter crops. Table 2 illustrates how the area of enterprises varies throughout models.

Table 1. Treatment explanations details and components of various IFS models.

IFS Model	C_1	C_2	C_3	C_4	G	H	N	P	S_1	S_2
M_1	‡									
M_2	‡	‡	‡							
M_3	‡	‡		‡			‡		‡	
M_4	‡	‡	‡	‡				‡		
M_5			‡		‡	‡	‡			‡
M_6	‡		‡		‡			‡		
M_7	‡	‡		‡		‡	‡	‡		‡

C_1: Rice − Groundnut; C_2: Pigeonpea + Sweetcorn (1:3) − Pearl millet; C_3: Bt cotton + Greengram (1:2) − Maize; C_4: Pigeonpea + Maize (1:3) − Sunhemp; G: Guava; N: Napier grass; H: Hedge lucerne; P: Poultry; S_1: Sheep unit I; S_2: Sheep unit II. ‡ indicates presence of that particular component in the model.

Table 2. 1 Acre farm treatments for IFS.

IFS Model	Components	Area
M_1	Rice with Groundnut	4000 sq.m
M_2	Rice – Groundnut Pigeonpea + Sweetcorn (1:3) − Pearl millet Bt cotton and greengram in a 1:2 ratio with maize	1000 sq.m 1000 sq.m 2000 sq.m
M_3	Rice with Groundnut Pigeonpea with Sweetcorn (1:3) − Pearl millet Pigeonpea with Maize (1:3) − Sunhemp Napier grass	1500 sq.m 1000 sq.m 1000 sq.m 500 sq.m
M_4	Rice with Groundnut Pigeonpea with Sweetcorn (1:3) − Pearl millet Pigeonpea with Maize (1:3) − Sunhemp Bt cotton and greengram in a 1:2 ratio with maize	1000 sq.m 1000 sq.m 1000 sq.m 1000 sq.m
M_5	Guava Hedge lucerne Napier grass Bt cotton and greengram in a 1:2 ratio with maize	2000 sq.m 500 sq.m 500 sq.m 1000 sq.m
M_6	Guava Bt cotton and greengram in a 1:2 ratio with maize Rice − Groundnut	2000 sq.m 1000 sq.m 1000 sq.m
M_7	Rice − Groundnut Pigeonpea with Sweetcorn (1:3) − Pearl millet Pigeonpea and Maize in a 1:3 ratio, accompanied by Sunhemp. Napier grass Hedge lucerne	1000 sq.m 1000 sq.m 1000 sq.m 500 sq.m 500 sq.m

2.4. *Agronomic Practices*

Tractor-drawn implements were used to prepare the land and perform the majority of intercultural activities on all crops. The recommended plant spacing was followed while sowing each crop (Table 3). Hand labor was used for the planting of rice and the sowing of the remaining crops. A power weeder and wheel hoe were used for weed management, and pesticides tailored to a certain crop were used for protection. Three replications were created for each component region, and information was gathered from each replication.

Table 3. Recommended package of practices of all crops in integrated farming system.

S.No.	Name of the Crop	Season	Seed Rate acre^{-1}	Fertilizer Dose acre^{-1} (N:P:K)	Variety
1	Rice	Rainy season	10	48:24:16	RNR 21278
2	Groundnut	Winter	60	8:20:12	K-6
3	Pigeonpea	Rainy season	2	8:20:12	WRG-97
4	Sweetcorn	Rainy season	4	80:24:16	Sugar 75
5	Pearl millet	Summer	1.5	33:16:12	MPMH 21
6	Bt Cotton	Rainy season	1	60:24:24	Magna (RCH 530 BG II)
7	Greengram	Rainy season	6	8:20:12	WGG 42
8	Maize	Winter	8	96:33:24	Pioneer 3396
9	Pigeonpea	Rainy season	2	8:20:12	WRG-97
10	Maize	Rainy season	8	96:33:24	Pioneer 3396
11	Sunhemp	Summer	16	4:8:0	Local
	Fodder crops				
11	Hedge Lucerne	Perennial	8 kg	12:24:8	RL-88
12	Hybrid napier	Perennial	7408 cuttings	75:24:24	Super napier
	Horticultural crops				
13	Guava	Perennial		40:16:40	Allahabad Safeda

2.5. Economic Analysis

Cost of production and gross returns were computed using the current market prices for inputs and outputs. In India, the government has set a minimum wage rate, and no worker should be paid less than this amount since it is the basis for calculating worker salaries. There were two categories of costs in the IFS cost component: fixed costs and variable costs. Variable costs are included in the price of inputs such as labor costs, fertilizers, herbicides, pesticides, plowing, irrigation, and seeds. The fixed cost is the one-time initial investment, particularly for perennial components, building an animal shelter, buying animals, planting guava, etc. Ultimately, the ratio of benefit cost (gross returns divided by cost of production) and net return (gross return less total cost) were computed.

$$\text{Net return } (₹) = \text{Gross returns } (₹) - \text{Total cost of production } (₹) \tag{1}$$

$$Benefit\ cost\ ratio\ (B:C) = \frac{Gross\ returns\ (₹)}{Total\ cost\ of\ production\ (₹)} \tag{2}$$

System Economic Efficiency

The daily net earnings were ascertained by evaluating the system's economic efficiency (SEE). SEE was determined by dividing the annual net returns from an IFS model by 365. The calculation was performed via the subsequent formula.

$$SEE = \frac{Net\ returns\ per\ year\ (₹)}{365\ days} \tag{3}$$

2.6. Energetics

Input energy includes all the resources utilized in the production of crops and livestock. Output energy includes the energy production of grain, straw yields, livestock meat, and manure. In economic terms, input and output energy are the cost of cultivation and gross returns, respectively. The energy equivalents of all inputs used by the system, represented in MJ per unit area, are added up to determine the system's total energy input.

Similarly, utilizing certain energy factors, the total yields of grain, straw, livestock meat, and manure across all crop commodities and livestock components were first translated into a rice equivalent yield and then into energy terms (MJ unit area^{-1}). After that, the energy equivalents of grain, straw yields, livestock meat, and manure are added up to determine the overall energy production. The following formulas were used to calculate and compare net energy (MJ), energy consumption efficiency, energy productivity (kg MJ^{-1}), and specific energy (MJ kg^{-1}).

$$\text{Energy use efficiency} = \frac{\text{Output energy }(\text{MJ unitarea}^{-1})}{\text{Input energy }(\text{MJ unitarea}^{-1})} \tag{4}$$

$$\text{Net energy }(\text{MJ ha}^{-1}) = \text{Output energy }(\text{MJ ha}^{-1}) - \text{Input energy }(\text{MJ ha}^{-1}) \tag{5}$$

$$\text{Energy productivity }(\text{kg MJ}^{-1}) = \frac{\text{Crop yields }(\text{kg ha}^{-1})}{\text{Input energy }(\text{MJ ha}^{-1})} \tag{6}$$

$$\text{Specific energy }(\text{MJ ha}^{-1}) = \frac{\text{Input energy }(\text{MJ ha}^{-1})}{\text{Output }(\text{kg ha}^{-1})} \tag{7}$$

2.7. Greenhouse Gas Emissions

The assessment of greenhouse gas (GHG) emissions from various components of the agricultural system was performed utilizing the IFS-GHG Estimation Tool, created by the ICAR-Indian Institute of Farming Systems Research [15]. This tool facilitates the assessment of greenhouse gas emissions at the farm level, covering the complete process from production to harvest. It consists of a standardized collection of empirical models intended to estimate emissions at the farm level, classifying emission sources into specific categories to enable the convenient quantification of significant emissions of CO_2, CH_4, and N_2O. This tool presents greenhouse gas (GHG) emissions in CO_2 equivalent per unit of crops and per capita for animals, utilizing the 100-year global warming potentials employed in national GHG accounting as specified by [16].

The cumulative amount of greenhouse gas emissions produced during the cropping period from a system is referred to as the carbon footprint and is quantified in kilograms of CO_2 equivalent.

Carbon footprints in system productivity (CF_{SP}) are kg of GHG emissions emitted for each kg of system production and is calculated using the following formula [17].

$$\text{CF}_{SP}\ (kg\ kg^{-1}) = \frac{\text{Total GHG emissions }(\text{kg CO}_2\text{ eq.})}{\text{System productivity }(\text{kg})} \tag{8}$$

Eco-Efficiency Index

Assessing the eco-efficiency index (EEI) is crucial for the development of environmentally sustainable production systems. The EEI evaluates the system's ability to generate economic returns while minimizing environmental disruption. A production system characterized by environmental soundness typically exhibits a higher EEI, achieved through the reduction in adverse environmental impacts and the enhancement of net economic gains [18]. In this study, the ecological implications of various IFS models were evaluated based on economic gains in relation to total GHG emissions (measured in kg CO_2 eq.). EEI was calculated with the following formula:

$$\text{EEI }(₹\text{ kg CO}_2\text{ eq.}^{-1}) = \frac{\text{Net returns }(₹)}{\text{GHG emission }(\text{kg CO}_2\text{ eq.})} \tag{9}$$

2.8. Employment Generation (Man-Days ha^{-1} Year^{-1})

The labor requirement for different activities was recorded and given in man-days ha^{-1} year^{-1}. A person working for 8 h in a day was considered one man-day. Man-days were calculated for components separately as well as all treatment combinations and compared. A cropping system or farming system with more man-days indicates that more employment opportunities are created, which can be seen as positive indicator.

2.9. Statistical Analysis

The one-way "Analysis of Variance" (ANOVA) method of randomized block design [19] was used in three replications with seven treatments to statistically assess the data. The Fisher-Snedecor "F" test error mean square at a probability level of 0.05 was used to assess the importance of different causes of variances. Using GRAPES software 1.0.0 [20], the critical difference (CD) and the standard error of mean (SEm±) at the 5% level of significance were calculated for each character and included in the results tables to compare the differences between the treatment means. Additional data are made available in the Supplementary Materials.

3. Results and Discussion

3.1. Economic Indicators of Different IFS Models

Mean net returns were obtained in the order of M_7 (₹124,953) > M_3 (₹96,248) > M_5 (₹93,583) > M_4 (₹66,683) >M_1 (₹53,516) > M_2 (₹53,000) > M_6 (₹50,638) (Figure 4). Because these models (M7 and M3) feature many enterprises that interact in a complementary way and generate money all year round, as opposed to conventional systems, they yield higher incomes. Because they are in high demand and can be produced year-round, sheep and napier grass have contributed the majority of the income. These findings are consistent with those of [17,21], who discovered that the interaction of several enterprises, such as crops, cattle, and poultry, is mostly responsible for the greater returns in integrated farming systems.

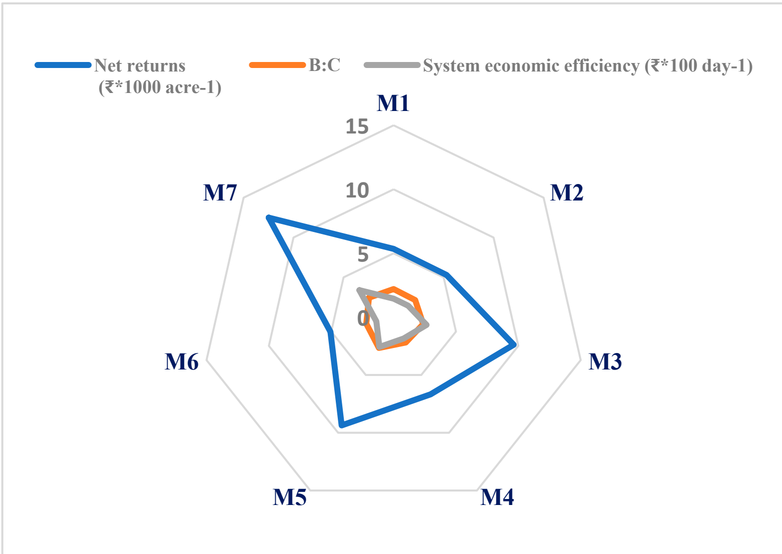

Figure 4. Economic indicators of different IFS models.

Models with only cropping systems (M_1 and M_2) have recorded lower returns in both the years, which indicates the importance of livestock as reported by [22]. Model M_5 had recorded a higher B:C of 2.31 and 3.05 in both the years, respectively, with a mean ratio of 2.64 compared to other models because of lower cost of production and higher returns. Model M_6 has recorded lower returns in both years because of the poor performance of the guava orchard. When compared to the M_1 model, the model M_7 showed mean increases in gross and net returns of 116 and 133%, respectively. Reference [23] observed that in an integrated agricultural system compared to the farmer's practice, gross and net income increased by 397 and 447%, respectively. These findings corroborate the findings of the study.

Among all the models, the highest mean system economic efficiency (₹342.3 day^{-1}) was recorded in model M_7 followed by M_3 (₹263.7 day^{-1}) and M_5 (₹256.4 day^{-1}) (Figure 4). Because of their numerous successful businesses, particularly those related to sheep and napier grass, Models M_7, M_3, and M_5 have a higher system economic efficiency. Kharche et al. [24] found that the crop + horticulture + diary + goat + poultry + vermicompost model had the highest system economic efficiency at ₹1257 day^{-1}. This model was followed by crop + horticulture + goat + poultry + vermicompost, which obtained ₹1118 day^{-1} due to the integration of multiple profitable enterprises, such as goat and poultry. These results are consistent with their findings.

Model M_6 had recorded minimum mean system economic efficiency of ₹138.7 day^{-1}, which is attributed to low returns from the guava orchard followed by M_2 (₹145.2 day$^{-1)}$ and M_1 (₹146.6 day^{-1}). The aforementioned results are corroborated by [25], who found that integrated farming systems achieve ₹353 ha^{-1} day^{-1}, while conventional rice–wheat systems achieve ₹132 ha^{-1} day^{-1}. The integration of livestock in integrated farming systems also leads to higher system economic efficiency.

3.2. Energy Budgeting of Different IFS Models

Among all the models, the highest input energy (43,369 and 75,158 MJ), output energy (247,862 and 268,503), and net energy gain (204,495 and 193,345) were obtained in the model M_7 in both years, respectively, followed by M_3, which had an obtained input energy of 34,392 and 56,204, output energy of 222,106 and 234,951 MJ, and net energy gain of 187,715 and 178,747 MJ in both years, respectively (Table 4).

Table 4. Energy budgeting of different IFS models.

IFS Models	Input Energy (MJ)			Output Energy (MJ)			Net Energy Gain (MJ)		
	2021–2022	2022–2023	Mean	2021–2022	2022–2023	Mean	2021–2022	2022–2023	Mean
$\mathbf{M_1}$: C_1	21,172	21,512	21,342	98,896	104,364	101,630	77,724	82,852	80,288
$\mathbf{M_2}$: $C_1 + C_2 + C_3$	22,764	22,725	22,745	116,080	131,544	123,812	93,316	108,819	101,068
$\mathbf{M_3}$: $C_1 + C_2 + C_4 + N + S_1$	34,392	56,204	45,298	222,106	234,951	228,529	187,715	178,747	183,231
$\mathbf{M_4}$: $C_1 + C_2 + C_3 + C_4 + P$	28,506	28,676	28,591	129,101	142,213	135,657	100,595	113,537	107,066
$\mathbf{M_5}$: $G + H + N + C_3 + S_2$	28,587	60,087	44,337	169,466	183,753	176,610	140,880	123,666	132,273
$\mathbf{M_6}$: $G + C_1 + C_3 + P$	20,311	20,461	20,386	52,589	57,496	55,043	32,278	37,035	34,657
$\mathbf{M_7}$: $C_1 + C_2 + C_4 + H + N + S_2 + P$	43,369	75,158	59,263	247,863	268,503	258,184	204,495	193,345	198,920
SEm (±)	1630	2329	-	6613	6878	-	5323	5166	-
C.D (p = 0.05)	5021	7177	-	20,378	21,193	-	16,403	15,918	-

The higher output energy as well as net energy gain in both models were mainly due to the napier grass and cropping components, which are highly energy efficient.

The presence of several energy-efficient components in these two models has resulted in increased output energy and net energy gain. Kumar et al. [26] & Pasha et al. [27] indicated that the total net energy gain in an integrated farming system is superior to that of conventional systems, owing to energy savings in the crop sector that counterbalance the negative energy consumption associated with sheep and poultry components.

Model M_3 had obtained the highest energy use efficiency (6.46) in the first year, but model M_2 had obtained the highest energy use efficiency (5.79) in the second year, which is mainly because of the high input energy requirement for the former model in the second year. Models M_1 (0.228 and 0.229 kg MJ^{-1}; 4.38 and 4.36 MJ kg^{-1}) and M_6 (0.223 and 0.236 kg MJ^{-1}; 4.49 and 4.25 MJ kg^{-1}) have recorded high energy productivity and low specific energy, which are significantly on par with M_2 (0.204 and 0.232 kg MJ^{-1}; 4.90 and 4.32 MJ kg^{-1}) and M_4 (0.210 and 0.223 kg MJ^{-1}; 4.76 and 4.49 MJ kg^{-1}) (Table 5). The high energy productivity and low specific energy obtained in these models are mainly due to the high RGEY as well as low input energy. Channabasavanna et al. [28] noted that the energy use efficiency of the conventional rice–rice system was high as compared to the integrated farming system, as goats and poultry were less energy efficient.

Table 5. Energy use efficiency, productivity, and specific energy of different IFS models.

IFS Models	Energy Use Efficiency			Energy Productivity (kg MJ^{-1})			Specific Energy (MJ kg^{-1})		
	2021–2022	2022–2023	Mean	2021–2022	2022–2023	Mean	2021–2022	2022–2023	Mean
$\mathbf{M_1}$: C_1	4.67	4.85	4.76	0.228	0.229	0.229	4.38	4.36	4.37
$\mathbf{M_2}$: $C_1 + C_2 + C_3$	5.10	5.79	5.44	0.204	0.232	0.218	4.90	4.32	4.59
$\mathbf{M_3}$: $C_1 + C_2 + C_4 + N + S_1$	6.46	4.18	5.05	0.223	0.141	0.172	4.49	7.07	5.81
$\mathbf{M_4}$: $C_1 + C_2 + C_3 + C_4 + P$	4.53	4.96	4.74	0.210	0.223	0.216	4.76	4.49	4.62
$\mathbf{M_5}$: $G + H + N + C_3 + S_2$	5.93	3.06	3.98	0.225	0.125	0.157	4.44	7.99	6.35
$\mathbf{M_6}$: $G + C_1 + C_3 + P$	2.59	2.81	2.70	0.223	0.236	0.231	4.49	4.25	4.34
$\mathbf{M_7}$: $C_1 + C_2 + C_4 + H + N + S_2 + P$	5.72	3.57	4.36	0.219	0.139	0.168	4.57	7.18	5.94
SEm (±)	0.18	0.16	-	-	0.008	-	-	0.24	-
C.D (p = 0.05)	0.56	0.51	-	NS	0.026	-	NS	0.75	-

NS—Non significant.

Input (20,311 and 20,461 MJ), output (52,589 and 57,496 MJ), net energy gain (32,278 and 37,035 MJ), and energy use efficiency (2.59 and 2.81) were the lowest for Model M_6 among all the models, which might be due to low maintenance, labor requirements, and low fruit yield in the guava orchard. The lowest energy productivity and high specific energy were obtained in M_5 (0.225 and 0.125 kg MJ^{-1}; 4.44 and 7.99 MJ kg^{-1}) and M_7 (0.219 and 0.139 kg MJ^{-1}; 4.57 and 7.18 MJ kg^{-1}) in both years, respectively (Table 5), which might be because of having guava orchards and sheep in M_5 and sheep and poultry components in M_7. Energy productivity severely decreased in the second year in the IFS models with sheep components (M_3, M_5 and M_7) compared to the first year because of an increase in the sheep number in the second year, which led to high input energy consumption in the form of feed. Sheep and poultry components had obtained a higher negative energy gain, low energy use efficiency, and higher specific energy, which might be due to green fodder, dry fodder, and silage being fed to sheep, which were composed of higher energy, and meat, as well as manure, which is composed of low energy. These findings align with those of [29,30] who observed that fodder crops exhibited the highest energy use efficiency, followed by field crops. Conversely, goat, sheep, and poultry rearing were noted to be less energy efficient, requiring greater energy inputs in the form of feed, with their feeds demonstrating a lower energy efficiency. Shekinah [31] found that having livestock components produces the highest energy output but reduces energy productivity as well as efficiency, mainly because of their high input energy requirements.

3.3. Greenhouse Gas Emissions

Higher negative net emissions of −3315 kg CO_2 eq. were obtained in model M_7, which was on par with M_5 (−3045 kg CO_2 eq.) in the first year, whereas in the second year, higher negative net emissions of −2732 kg CO_2 eq. were obtained in model M_5, which is on par with M_2 (−2545 kg CO_2 eq.) (Figure 5). Models with sheep components recorded higher emissions in the second year, leading to lower net negative emissions, which is because of the increase in sheep numbers. Higher mean net negative emissions were obtained in model M_7 (−2803 kg CO_2 eq.), followed by M_4 (−2542 kg CO_2 eq.), and M_5 (−2383 kg CO_2 eq.) (Figure 5). The inclusion of multiple enterprises or components within an IFS model increases its ability to act as a sink, resulting in negative net emissions. Swarnam et al. [32] and Meena et al. [33], who discovered that increasing crops and other components increases the carbon sink and renders farming systems environmentally benign, corroborate this finding.

Figure 5. Net GHG emissions from different IFS models.

Model M_1 has obtained lower negative net emissions of −284, −376, and −330 kg CO_2 eq. in 2021–2022, 2022–2023, and mean, respectively, among all the models. This phenomenon could be attributed to the fact that rice typically emits more GHGs and has a lower sink capacity than other crops, resulting in diminished negative net emissions. Islam et al. [34] noted that wetland paddy cultivation contributes to GHG emissions, suggesting the combination of paddy production and livestock components, i.e., ducks and fish, as a strategy to mitigate GHG emissions.

3.4. Carbon Footprints in System Productivity (CF_{SP})

The total extent of GHG emissions emitted throughout the cropping period from a system is known as the carbon footprint and is expressed as kg CO_2 eq. Carbon footprints in system productivity (kg kg^{-1}) are the kg of GHG emissions emitted for each kg of system production. Among all the models, M_7 (0.155 kg kg^{-1}) and M_4 (0.155 kg kg^{-1}) have recorded the lowest CF_{SP}, which is significantly on par with models M_6 (0.160 kg kg^{-1}) and M_5 (0.166 kg kg^{-1}) in the first year, but in the second year, emissions increased in models M_7 and M_5 because of an increase in the sheep number, which led to higher CF_{SP} (Table 6). M_4 recorded the lowest CF_{SP} (0.147 kg kg^{-1}), which is significantly on par with M_6 (0.154 kg kg^{-1}) in the second year. Overall, models M_4 and M_6 have obtained low CF_{SP} compared to other models, which might be due to the fact that having only crop and poultry components resulted in lower emissions in both years.

Table 6. Carbon footprints in system productivity of different IFS models.

IFS Models	Source (kg CO_2 eq.)			System Productivity (kg)			CF_{SP} (kg kg^{-1})		
	2021–2022	2022–2023	Mean	2021–2022	2022–2023	Mean	2021–2022	2022–2023	Mean
M_1: C_1	1584	1616	1600	4836	4936	4886	0.328	0.327	0.327
M_2: $C_1 + C_2 + C_3$	967	980	974	4648	5264	4956	0.208	0.186	0.197
M_3: $C_1 + C_2 + C_4 + N + S_1$	1639	2754	2197	7653	7948	7800	0.214	0.347	0.280
M_4: $C_1 + C_2 + C_3 + C_4 + P$	927	939	933	5987	6382	6185	0.155	0.147	0.151
M_5: $G + H + N + C_3 + S_2$	1069	2492	1781	6439	7524	6982	0.166	0.331	0.249
M_6: $G + C_1 + C_3 + P$	724	741	733	4520	4819	4670	0.160	0.154	0.157
M_7: $C_1 + C_2 + C_4 + H + N + S_2 + P$	1473	2897	2185	9493	10,468	9981	0.155	0.277	0.216
SEm (±)	50.22	80.66	-	336	355	-	0.008	0.010	-
CD (p = 0.05)	154.8	248.6	-	1035	1092	-	0.026	0.033	-

Model M_1 has recorded higher CF_{SP} in both years (0.328 and 0.327 kg kg^{-1}), which is attributed to higher methane emissions from rice, followed by model M_3 (0.214 and 0.347 kg kg^{-1}). The higher CF_{SP} from model M_3 is due to having rice crops in more areas and sheep components. These findings are supported by [17,35], who noticed that higher CF_{SP} is obtained in models with sheep/goats and rice crops.

3.5. Eco-Efficiency Index

Model M_5 recorded a higher eco-efficiency index (EEI) of ₹78.7 kg CO_2-eq.$^{-1}$, followed by model M_7 (₹78.2 kg CO_2-eq.$^{-1}$) in the first year, which is due to lower emissions from M_5 and higher net returns of model M_7 (Figure 6). But in the second year, Model M_4 recorded a higher EEI of ₹77.7 kg CO_2 eq.$^{-1}$, which was significantly on par with M_6 (₹74.5 kg CO_2 eq.$^{-1}$). Emissions from models with sheep components, i.e., M_7, M_5, and M_3 increased in the second year, which is the reason for the low EEI of these models. Model M_4 had recorded a higher mean EEI (₹71.4 kg CO_2 eq.$^{-1}$) followed by models M_6 (₹69.1 kg CO_2 eq.$^{-1}$) and M_7 (₹62.4 kg CO_2 eq.$^{-1}$).

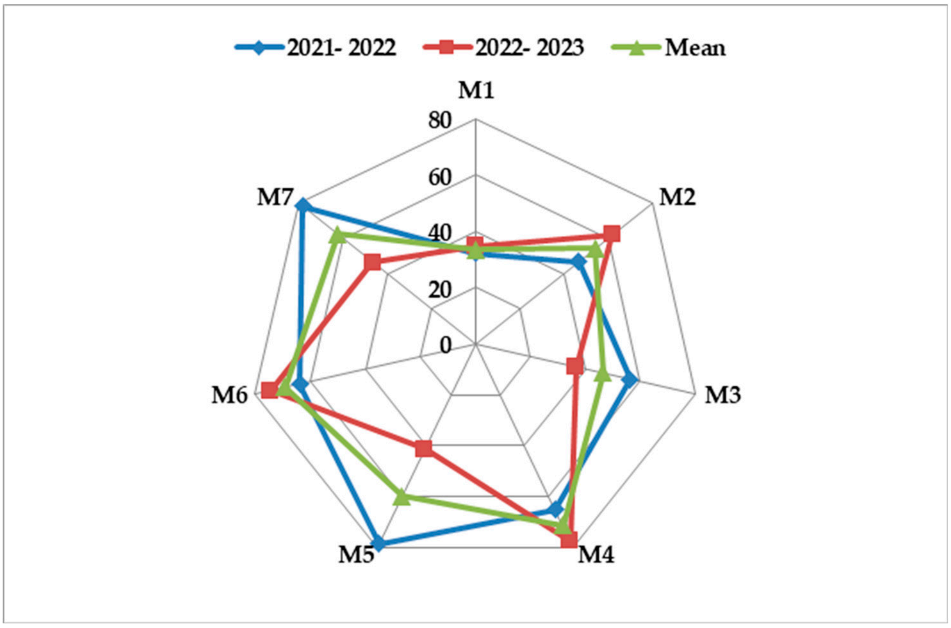

Figure 6. Eco-efficiency index (EEI) of different IFS models.

Compared to all models, Model M_1 had obtained a lower EEI of ₹32.2 and 34.7 kg CO_2 eq.$^{-1}$ in both years, respectively, whereas a mean EEI of ₹33.4 kg CO_2 eq.$^{-1}$ was obtained. It might be attributed to low net returns and higher GHG emissions from the model M_1. Fatima et al. [9] and Babu et al. [18] reported that farming systems with diverse and multiple components achieve better results than traditional cropping systems, and IFS achieves environmental efficiency by yielding higher economic returns per unit of GHG emissions.

3.6. Employment Generation

Model M_7 generated 98 man-days year^{-1}, which was significantly on par with M_3 and M_4, which generated 97.5 and 87 man-days year^{-1}, respectively, in the first year (Table 7). In the second year, M_7 generated 127 man-days per year, which is significantly on par with M_3, which generated 123.5 man-days per year. The mean employment generation of M_7 was 112.5 man-days per year, which is significantly on par with that of M_3, which generated 110.5 man-days per year. The higher employment generation of the M_7 and M_3 models is mainly because they have multiple enterprises, especially the sheep component. Patel et al. [12] predicted that IFS models generate more employment opportunities compared to conventional cropping systems, primarily due to the greater number of enterprises involved and the need for their maintenance.

Table 7. Employment generation in different IFS models.

IFS Models	Employment Generation (Man-Days Year^{-1})		
	2021–2022	2022–2023	Mean
$\mathbf{M_1}$: C_1	84	92	88
$\mathbf{M_2}$: $C_1 + C_2 + C_3$	85	91	88
$\mathbf{M_3}$: $C_1 + C_2 + C_4 + N + S_1$	97.5	123.5	110.5
$\mathbf{M_4}$: $C_1 + C_2 + C_3 + C_4 + P$	87	89	88
$\mathbf{M_5}$: $G + H + N + C_3 + S_2$	62	94	78
$\mathbf{M_6}$: $G + C_1 + C_3 + P$	57	62	59.5
$\mathbf{M_7}$: $C_1 + C_2 + C_4 + H + N + S_2 + P$	98	127	112.5
SEm (±)	3.89	4.57	4.35
CD (p = 0.05)	12.01	14.10	13.4

The employment generation of Model M_6 was less compared to all other models, and it generated 57 and 62 man-days per year in both years, respectively, and the mean employment generation was 59.5 man-days per year. This may be because of the lower labor requirements of guava orchards as well as poultry. Although the model M_5 has a sheep component, employment generation was lower (62, 94, and 78 in 2021–2022, 2022–2023, and mean) because of the lower labor requirements of the guava orchard, hedge lucerne, and hybrid napier. The conventional model M_1 generated 84 and 92 man-days per year in both years, respectively, and the mean employment generation was 88 man-days per year.

Employment generation was limited to sowing, intercultivation, and harvesting operations in conventional cropping systems. The mean employment generation of models M_7 and M_3 was 27.8 and 25.6% higher compared to conventional models M_1. Employment opportunities were significantly enhanced due to the diversification of sole cropping to the IFS model. Similar results were observed by [22,36], who demonstrated that integrating livestock production with field crops generates 43–55% higher employment compared to sole cropping. Ranking table of IFS models regarding different indicators can be seen in Table 8.

Table 8. Ranking table of IFS models regarding different indicators.

Indicator	M_1	M_2	M_3	M_4	M_5	M_6	M_7
Net returns and System economic efficiency	5	6	2	4	3	7	1
Net energy gain	6	5	2	4	3	7	1
Energy use efficiency	3	1	2	4	6	7	5
Net GHG emissions	7	3	5	2	4	6	1
Carbon Footprints$_{(SP)}$	7	3	6	1	5	2	4
Eco Efficiency Index	7	5	6	1	4	2	3
Employment generation	3	3	2	3	6	7	1

4. Conclusions

There is a need to develop energy-efficient and climate-smart farming practices that maintain sustainability, particularly for those regions that are dominated by rice cropping systems. Small and marginal farmers practice conventional rice cropping systems in Telangana and surrounding regions, which poses a challenge to the environment in the long term, and farming systems with suitable components could be a solution for this challenge. An integrated farming system fosters a crop ecosystem characterized by enhanced CO_2 absorption and reduced emissions, thereby conferring greater climate resilience compared to conventional cropping systems. It produces more by utilizing minimal inputs, which makes it energy efficient. Various integrated farming system models are compared with the conventional models used in Telangana in this experiment to identify the most climate-resilient and energy-efficient model. Among all the integrated farming system models, M_7 has obtained the highest net returns, output energy, as well as net energy gain in both years, followed by M_3. M_7 has recorded higher mean negative net emissions, followed by M_4 and M_3, which suggests that incorporating multiple enterprises enhances the capacity of the system to act as a sink, resulting in higher negative net emissions. The mean employment generation of M_7 was high, which is significantly on par with M_3. The higher employment generation of the M_7 and M_3 models is mainly because they have multiple enterprises, especially the sheep component. The mean employment generation of models M_7 and M_3 is 27.8 and 25.6% higher compared to conventional models M_1. M_7 and M_3 models are suitable for Telangana and its surrounding regions as both are climate resilient, profitable, energy efficient, and also provide more employment generation.

Future lines of work

- To identify better greenhouse gas (GHG) mitigation strategies.
- To identify the more energy-efficient practices in an integrated farming system.
- To work on the same model across Telangana and compare the results.
- To establish a comprehensive understanding of farming systems, it is essential to create a database encompassing various types of farming systems, infrastructure details, economic aspects, and sustainability indicators.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su162310189/s1, File S1: Prevailing market prices for crop inputs during 2021–2022 and 2022–2023; File S2: Prevailing market selling price for output (main and by-products) during 2021–2022 and 2022–2023; File S3: Prevailing market prices for livestock inputs, outputs (products and by-products) and fixed costs; File S4: Equivalent energy of different inputs used for energy analysis in IFS model; File S5: Equivalent energy of different outputs used for energy analysis in IFS model; Table S1: Economics of various components in IFS model; Table S2. Energetics of individual components of IFS Model.

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