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Paddy-based Cropping Systems and their Sustainability: A Micro-level Study of Nellore District of Andhra Pradesh, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A sustainable cropping system is needed to ensure profitable, productive and less risky crop production, particularly when the agricultural sector is experiencing climatic uncertainty and price volatility. Hence, the study aims to identify paddy-based cropping systems and their sustainability in the Nellore district of Andhra Pradesh. The study is based on primary data collected during 2022-23 with the help of a pre-structured schedule. The major cropping systems based on paddy were identified as system Ⅰ (paddy-groundnut), cropping system Ⅱ (paddy-paddy), & cropping system

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Ⅲ (paddy-cotton). The profitability analysis revealed that the gross returns for cropping systems I, II and III were computed to be Rs. 281916.83, Rs. 259072.90 and Rs. 330072.45. The farmers realized the highest net income, Rs. 169222.62, under cropping system III. The net returns for the cropping systems Ⅰ and Ⅱ were obtained as Rs. 141282.24 and Rs. 127048.48, respectively. The sustainability indices of paddy-groundnut (cropping system I), paddy-paddy (cropping system II) and cropping system III (paddy-cotton) were computed as 42.88%, 50.86% and 60.93%, respectively, and the paddy-cotton cropping system came out as the most profitable and sustainable in the study area. The regression analysis revealed that factors like returns to cost ratio and the cost used for environmentally friendly inputs relative to the overall cost of cultivation were found significant in all three cropping systems.

Keywords: Paddy; cotton; groundnut; cropping system; sustainability.

1. INTRODUCTION

In India, agriculture is vital to people's livelihood, as 60% of the population depends on agriculture and related livelihood opportunities. Agriculture directly employs nearly two-thirds of the Indian population. It serves as India's economy's central pillar, and further, agriculture and allied sectors contribute around 20% of the total gross value added (GVA) of India's economy. Food grain production has reached about 350 million tonnes. The output of wheat, paddy, and other coarse cereals has expanded at compound annual growth rates (CAGR) of 2.9%, 2.7%, and 4.8%, respectively, over the past six years from 2015-16 to 2020-21 [1].

Farmers typically cultivate a few selected crops, resulting in continuous monocropping. Continuous monoculture reduces the soil's fertility level, and over time, the soil loses its ability to absorb fertilizer and loses its ability to produce. Therefore, maintaining soil fertility is necessary to achieve and improve stable food production, and further Cropping systems help maintain soil nutrients. Demand for food is rising with population, so the challenge of increasing food production with limited land resources arises. Efficient use of the available resources is essential for this. The aim of cropping systems is the maximum utilization of every resource.

A cropping system refers to the collection of crop systems that comprises the cropping activities of a farm system. It includes crop rotation, crop diversification intercropping and related farming practices that affect soil health [2]. Initially, the cropping system aimed to maximize crop yield, but later on, environmental sustainability and stable productivity concerns came into account [3]. It consists of every element necessary for growing a specific crop and how these elements interact with the environment (Technical Advisory Committee, Consultative Group on International Agricultural Research, 1978).

Paddy is the most significant and widely produced food crop worldwide. More than one-third of the world's population relies primarily on it. Paddy cultivation occupies 11% of the agricultural area in the world. Paddy is a staple food for more than 60% of South East Asia's population. In Southeast Asia, paddy, maize, and wheat are the three principal cereals contributing to income and food security. In South Asian tropical and subtropical climates, these crops are either produced as monocultures or in crop rotations. Paddy-paddy, paddy-wheat, and paddy-maize are the primary cropping systems in beneficial rainfed lowland and irrigated areas.

Despite having the largest paddy-growing area in the world (44 million hectares), India produces less paddy than China because of India's low productivity. Many Indian states cultivate paddy throughout the rabi season, while paddy is mainly grown during the Kharif season. The proportion of irrigated paddy land differs in every state, from 50% in Madhya Pradesh, Maharashtra, and Bihar to more than 90% in Andhra Pradesh, Haryana, Punjab, and Tamil Nadu. The current All India Coordinated Paddy Improvement Project at the Indian Institute of Paddy Research, Hyderabad, provides decadal changes in cropping systems research to establish a novel research method to boost the productivity of cropping systems depending on paddy [4].

When the paddy is grown continuously for extended periods with low system productivity and frequently using poor management techniques, soil fertility deteriorates due to numerous nutrient deficiencies. Deterioration of soil physical properties [5,6,7], drop in factor productivity and crop yields in high productivity areas [8], and decline in soil physical characteristics [9].

A paddy-centred cropping system can be defined as a combination of agricultural approaches, with paddy acting as the principal crop and other crops cultivated subsequently. One of India's most common cropping systems is crop rotation, which includes grains, pulses, oilseeds, cotton, sugarcane, green manures, vegetables, etc. There have been reports of numerous paddy-based cropping systems in India, including paddy followed by paddy and paddy in rotation with vegetables, fibre crops, cereals, pulses, and oil seeds. According to agro-ecosystems, farmers' convenience, market and household needs, and various cropping techniques are used in paddy-growing regions.

Years of cereal-cereal cultivation are now showing harmful effects on soil health, including changes to the soil's structure, poor drainage, and decreased total yield. Due to the heavy use of chemical fertilizers and irrigation, the soil became more salinized and did not respond well to further fertilizers [10]. The deterioration of soil health and human dietary pool are the consequences of continuous cereal farming [11].

Andhra Pradesh state is called the "Granary of South India" due to its vast surplus in the production of food crops. It is also referred to as South India's paddy bowl. The state exports around one-fifth of its paddy crop and is self-sufficient in food grains. The economy and people of Andhra Pradesh depend heavily on paddy. Paddy-paddy-pulses, paddy-cotton, and paddy-paddy-groundnut are the primary paddy-based cropping systems followed in coastal Andhra Pradesh. In cropping pattern, paddy shares 34.45%, followed by groundnut (11.73%), cotton (8.18%), Bengal gram (6.33%), black gram (5.31%) and maize (4.06%), respectively in Andhra Pradesh (Season and Crop Report, 2020-21, Directorate of Economics and Statistics, Planning Department (Government of Andhra Pradesh) [12].

Nellore region is among the highest paddy-growing districts in Andhra Pradesh. It holds the first position in the area under paddy cultivation but is fourth in production due to the yield gap, which is further due to the existing cropping systems in the district. In the Nellore district of Andhra Pradesh, there have been few research studies on cropping systems, while this approach to analyzing agricultural issues has gained popularity recently. Such a study will address the problems associated with different cropping systems and enable academics and policymakers to make region-specific recommendations that may be implemented for overall agricultural development in the Nellore region of Andhra Pradesh instead of general recommendations. This study aims to foster the income level of the farming community while maintaining the sustainable soil-water & environment relationship through efficiently utilizing available resources.

Hence, the study " **Paddy-based Cropping Systems and their Sustainability: A Micro-level Study of Nellore District of Andhra Pradesh**" was undertaken, which is crucial in developing, creating, and putting location-specific cropping systems into use in the study area and other areas with comparable circumstances. It would help farmers, academics, and politicians to decide the strategies that will eventually support the overall development of agriculture in the region, resulting in sustainable agricultural technologies and an improved environment.

2. METHODOLOGY

2.1 Selection of Study area and Respondents

The present study was undertaken during 2022-23. The Nellore district was purposefully selected for the current study since it is one of the main areas in Andhra Pradesh that produces paddy-based cropping systems. Out of the 46 mandals, three mandals, Kota, Vakadu, and Ananthasagaram, which follow cropping systems based on paddy, were selected for the current investigation. Further, a list of all villages with cropping systems centred on paddy was prepared from the three selected mandals, and two villages were chosen from each mandal for the study. From Kota mandal, the chosen villages were Kesavaram and Raghavapuram, and from Vakadu mandal, Venkannapalem and Nellipudi; from Ananthasagaram mandal, Venkatareddipalli and Kulluru. Twenty-five farmers were randomly chosen from each selected village. To evaluate various paddy-based cropping techniques, 50 respondents from every mandal served as the sample, and the overall sample size was 150 farmers.

Secondary data on various cropping systems on paddy was collected from the District Statistical Office to identify paddy-based cropping systems.

2.2 Sustainability of Different Cropping Systems and Factors Affecting It

To evaluate the sustainability of selected cropping systems in the study area, Boggia and Abbozzo's [13] Multi-Criteria Approach was adjusted to meet the farming conditions. Six factors- gross income per acre, the productivity of fertilizers and pesticides, the proportion of the cost of environmentally friendly resources to the total cost of cultivation, and the ratio of the cost of owned inputs to the total cost of cultivation were combined to create a composite sustainability index.

Gross income per acre indicator reflects how various farming practices affect production capacity.

Gross income per acre = $\frac{Value\ of\ total\ output}{Cultivated\ area\ in\ acre}$

Returns to Cost ratio reveals the farm's overall economic viability. The ratio needs to be higher than 1.0.

Returns to Cost ratio = $\frac{Value\ of\ total\ output}{Total\ cost\ of\ cultivation}$

Fertilizer productivity denotes the value of the product received for every rupee invested in fertilizer.

Fertilizer productivity = $\frac{Value\ of\ total\ output}{Total\ cost\ of\ fertilizer}$

Pesticide productivity represents the worth of the product received for every rupee invested in plant protection chemicals.

Pesticide productivity **=** $\frac{\mathbf{Value\ of\ total\ output}}{\mathbf{Total\ cost\ of\ pesticide}}$

The ratio of costs of eco-friendly inputs to the total cost of cultivation refers to environmentally friendly inputs like FYM, and the labour force can sustain agricultural production over time by keeping the surrounding environment healthy, slashed by the cost of cultivation. The higher percentage of these inputs implies that the cropping system is very sustainable.

The ratio of cost of owned inputs to the total cost of cultivation reveals that the value of own inputs to acquired inputs is greater, the condition can be considered sustainable because the crop relies heavily on internal resources.

The six indicators were converted into unit values (U_{ij}) using simple range and variability as the formula given below

$$U_{ij} = \frac{Y_{ij} - Min\ Y_j}{MaxY_j - \ MinY_j}$$

Where,
Y_{ij} is the value given by i^{th} respondent on j^{th} factor
Min Y_j is least score on j^{th} factor
Max Y_j is the highest score on j^{th} factor
U_{ij} is the unit value of i^{th} respondent on j^{th} factor

The range of the unit value varies between 0 and 1, in which unit value 1 indicates y_{ij} is the highest, and unit value 0 denotes the least value for y_{ij}.

Experts evaluate each indicator in descending order based on its relative value for sustainable use, and Garrett's ranking method is used to highlight its significance. Using Garrett's table, the percentage positions are transformed into scores on a scale of 100 points. The average score was produced from the acquired scores known as the scale value (S_j) of every factor in various crops. To calculate the sustainability index (SI_i) for each combination of crops, the unit values (U_{ij}) of each indicator are multiplied by the scale value of the corresponding component (S_j), added together, and divided by the overall scale value. The value of the Sustainability index is expressed in percentages. The greater the value of the index, the greater the sustainability.

$$SI_i = \frac{\sum_{i=1}^{n} U_{ij} * S_j}{\sum_{i=1}^{n} S_j}$$

Where,
U_{ij} = Unit value of the i^{th} respondent on the j^{th} component.
S_j = Scale value of each component.
SI_i= Sustainability index
Multiple regression analysis was used to determine the factors affecting sustainability. The general form of regression analysis is

$$Y_i = f(X_i, \beta) + e_i$$

Where,
Y_i = dependent variable
X_i = independent variable
β = unknown parameters
e_i = error terms

Garrett's ranking was adopted to determine the extent of influence of different factors. The sample respondents were given numbers like 1, 2, 3.... depending upon the number of respondents, giving 1(least) rank to the highest motivating factor and the largest rank to the least motivating factor. The order of merit as given by the sample respondents was changed to percentage position by using the following formula: -

$$\% \text{ Score} = \{100(R_{ij} - 0.5)\} / N_j$$

R_{ij} is the rank given by the i^{th} factor for the j^{th} respondent
N_j = number of factors ranked by the j^{th} respondent.

3. RESULTS AND DISCUSSION

3.1 Major Paddy-Based Cropping Systems Practised in the Study Area

Table 1 depicts the primary paddy-based cropping strategies used in the study region. The main crop of the district is paddy, followed by other crops like groundnut, cotton, pulses like Bengal gram, Black gram, etc. In the study area, it was identified that most of the farmers grew paddy, cotton, and groundnut. The farmers under the cropping system Ⅰ cultivated two crops yearly: paddy in rabi season and groundnut in summer. Farmers cultivated paddy in the cropping system Ⅱ in the kharif and rabi seasons. In contrast, under the cropping system Ⅲ, paddy was grown by the sample farmers in the kharif season, followed by cotton in the rabi and summer seasons. Banjara et al. [14] reported similar results.

3.2 General Characteristics of the Major Paddy-Based Cropping Systems

The major paddy varieties cultivated were RNR 15048, BPT 5206, and NLR 34449. The major groundnut variety was K-6, and the Cotton variety was Pradeep, Mudra. Kharif paddy variety duration was May-June to August-September, while rabi paddy was cultivated from November to March. The duration of the groundnut crop was from June to August, and for cotton, it was from October-November to April. Table 2 revealed the characteristics of major paddy-based cropping systems in the study area.

3.3 Costs and Returns of Different Crops under Identified Cropping Systems

The yield and returns (Table 3) depicted that the quantity of main product and by-product obtained from rabi paddy in cropping system Ⅰ was estimated at 64.35 qt/ha and 24.33 qt/ha, respectively, while the total gross returns gained from investment was Rs. 134065.53. Whereas, for the groundnut crop, the yield of the main product was observed to be 23.63 qt/ha and gross returns being Rs. 147851.30. Under the cropping system Ⅱ, even though paddy was grown in both kharif and rabi seasons, the difference in yields was observed with rabi paddy producing 65.08 qt/ha and kharif paddy (62.02 qt/ha). Further, the gross returns realized from paddy in the rabi season were highest (Rs. 133405.49), followed by paddy in the kharif season (Rs. 125667.41). Similarly, for crops like paddy and cotton in the cropping system III, the main product yield was 63.09 qt/ha and 32.09 qt/ha, respectively. The gross returns were maximum for cotton (Rs. 202167.00), followed by paddy (Rs. 127905.45).

3.4 Sustainability of Cropping Systems and Factors Affecting It in the Study Area

A composite sustainability index of the observed cropping systems in the study was calculated using a multi-criteria approach (Table 4). The sustainability index was created incorporating six components: gross income/acre, returns to cost ratio, fertilizer productivity, pesticide productivity, cost of ecosystem-friendly inputs to overall cost of cultivation, and the ratio of own inputs to total cost of cultivation. If the sustainability index of the cropping system is higher, it indicates that it is more sustainable.

Table 1. Major paddy-based cropping systems followed in the study area

Cropping season	Main crops		
	C.S. Ⅰ	**C.S. Ⅱ**	**C.S. Ⅲ**
Kharif	-	Paddy	Paddy
Rabi	Paddy	Paddy	Cotton
Summer	Groundnut	-	

Note: C.S.- Cropping system

Table 2. Characteristics of the major paddy-based cropping systems

Cropping System	Crop-Season	Sowing time	Harvesting time	Variety
CS I (Paddy-groundnut)	Paddy-Rabi	November	March	PNR-15048, BPT-5206
	Groundnut-Summer	June	August	K-6
CS II (Paddy-Paddy)	Paddy-Kharif	May-June	August-September	MTU-1010, KNM-1638
	Paddy-Rabi	November	March	NRL-34449, PNR-15048
CS III (Paddy-Cotton)	Paddy-Kharif	May-June	August-September	NLR-34449, PNR-15048, BPT-5206
	Cotton	October-November	April	Pradeep, Mudra

Table 3. Yield and returns of crops under different cropping systems

Crops	Main product (qt/ha)	Income from the main product (Rs)	By-Product (qt/ha)	Income from by-products (Rs)	Gross return (Rs/ha)
Cropping system Ⅰ					
Rabi paddy	64.35	131631.78	24.33	2433.75	134065.53
Groundnut	23.63	147851.30	-	-	147851.30
Cropping system Ⅱ					
Kharif paddy	62.02	122799.60	28.67	2867.81	125667.41
Rabi paddy	65.08	130834.22	25.71	2571.26	133405.49
Cropping System III					
Kharif paddy	63.09	125272.77	26.32	2632.68	127905.45
Cotton	32.09	202167.00	-	-	202167.00

In the study region, the sustainability of cropping system Ⅰ (paddy-groundnut) was calculated to be 42.88%. The sustainability of the cropping system Ⅱ, comprised of kharif paddy and rabi paddy, was 50.86%, and for the cropping system Ⅲ (paddy-cotton), the sustainability was estimated at 60.93%. As the gross returns per acre came out as one of the important factors for sustainability, which was observed to be the highest for the paddy-cotton system, it may be inferred that this cropping system was evaluated as the most sustainable and viable. Whereas, in the case of the paddy-groundnut system (cropping system Ⅰ), it was observed that sustainability was lower than that of the paddy-paddy system (cropping system Ⅱ) on account of factors like pesticide productivity and the ratio of cost of ecosystem-friendly inputs to the overall cost of cultivation was comparatively lower than the paddy-paddy system. Therefore, the cropping system Ⅱ was proved to be more sustainable than the cropping system Ⅰ. Moreover, the cropping system Ⅲ was found to be more sustainable in the study area succeeded by cropping system Ⅱ and cropping system Ⅰ; thus, this is suggested that the sample farmers should follow the paddy-cotton cropping system since it was found to be both profitable and sustainable system (Table 3). Melanie [15] and Ray et al. [16] reported similar findings.

3.5 Factors affecting the Sustainability in Different Cropping Systems in the Study Area

Linear multiple regression analysis was carried out to identify the factors affecting sustainability. The model used variables such as gross income per acre, returns to cost ratio, fertilizer productivity, pesticide productivity, the ratio of cost of environmentally friendly inputs to the total cost of cultivation, and the ratio of cost of owned inputs to the total cost of cultivation.

The results indicated that the Coefficient of Multiple Determinations (R^2) was estimated at 0.82, meaning 82% variation in sustainability was realized because of independent variables indicated in the cropping system Ⅰ (Table 5). The coefficient of gross income per acre was estimated at 0.185, which was positively significant at 5% significance level, implying that one per cent change in gross income per acre would result in 0.18 per cent increase in the sustainability of that cropping system. Similarly, the regression coefficients of variables like returns to cost ratio (0.446), pesticide productivity (0.258), and the ratio of cost of ecosystem-friendly inputs to total cost of cultivation (0.217) were found positively significant at 1 per cent level of significance, indicating 1% change on these variables would lead to positive change in sustainability by 0.44%, 0.25% and 0.21%, respectively. The regression coefficients of other variables like fertilizer productivity (0.105) and the ratio of cost of own inputs to total cost of cultivation (0.004) were found not significant; however, the value was positive.

The R^2 (coefficient of multiple determinations) the value obtained for the cropping system Ⅱ was 0.88. This implies that independent variables present in the model explained 88% of the variation in sustainability percentage. The regression analysis results under this cropping system demonstrated that the regression coefficients of variables like returns to cost ratio (0.259), fertilizer productivity (0.143), pesticide productivity (0.336), ratio of cost of eco-friendly inputs to total cost of cultivation (0.354), ratio of owned inputs to total cost of cultivation (0.183) were observed to be positively significant at 1% level of probability, depicting that 1% increase in these variables would lead to increase in sustainability of the cropping system by 0.25%, 0.14%, 0.33%, 0.35%, and 0.18% in corresponding order. Similarly, the coefficient of gross income per acre (0.064), which was one of the important factors in determining sustainability, was estimated to be positive but non-significant.

In the cropping system Ⅲ, the coefficient of multiple determination was 0.79, which explained 79% variation in the sustainability on account of independent variables included in the model. Similarly, coefficients of variables like gross income per acre (0.194), returns to cost ratio (0.290), fertilizer productivity (0.210), and the ratio of cost of environmentally friendly inputs to the total cost of cultivation (0.213) were observed to be positively significant at 1% level of significance. This implies that 1% increase in these variables enhances the sustainability of the cropping system by 0.19%, 0.29%, and 0.21%, respectively. Also, the regression coefficients of other factors, such as pesticide productivity (0.102) and the ratio of owned inputs to the total cost of cultivation (0.059), were positive; however, they were non-significant. Roy et al. [17] also reported similar findings in a study conducted in Bangladesh.

Table 4. Sustainability Index of the cropping systems in the study area

Sl. No.	Cropping system (C.S.)	Sustainability Index (S.I.)	Sustainability (%)
1	C.S. Ⅰ	0.4288	42.88
2	C.S. Ⅱ	0.5086	50.86
3	C S Ⅲ	0.6093	60.93

Table 5. Factors affecting the sustainability of cropping systems

Sl. no	Particulars	Cropping system Ⅰ	Cropping system Ⅱ	Cropping system Ⅲ
1	Intercept	0.0898	0.0487	0.0584
2	Gross income per acre	0.185 ** (0.0838)	0.064 (0.0565)	0.194 *** (0.0625)
3	Output-Input ratio	0.446 *** (0.1323)	0.259 *** (0.0535)	0.290 *** (0.0622)
4	Fertiliser productivity	0.105 (0.0719)	0.143 *** (0.0508)	0.210 *** (0.0808)
5	Pesticide productivity	0.258 *** (0.0477)	0.336 *** (0.0494)	0.102 (0.0534)
6	The ratio of the cost of ecosystem-friendly inputs to the overall cost of cultivation	0.217 *** (0.0543)	0.354 *** (0.0867)	0.213 *** (0.0608)
7	The ratio of the cost of owned inputs to the total cost of cultivation	0.004 (0.1025)	0.183 *** (0.0625)	0.059 (0.0570)
8	R^2	0.825	0.889	0.798

*Note: *** Significant at 1% level*
***Significant at 5 % level*

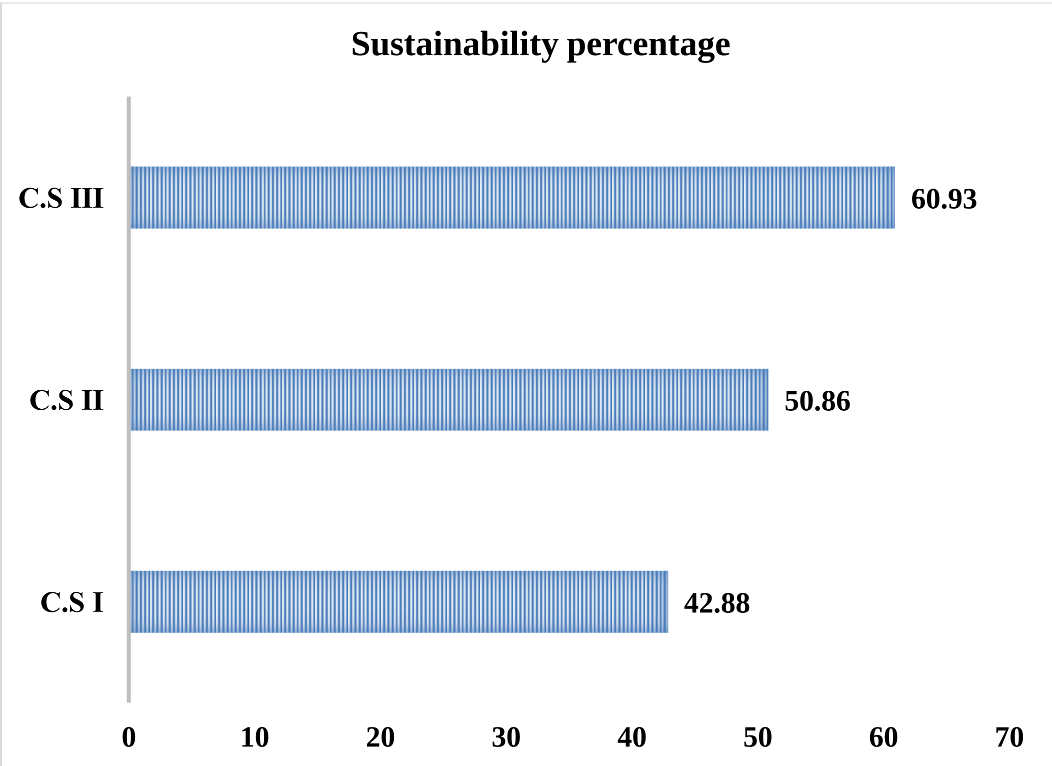

Fig. 1. Chart depicting sustainability of cropping systems

4. CONCLUSION

The major paddy-based cropping systems observed in the study region were paddy-groundnut (cropping system Ⅰ), paddy-paddy (cropping system Ⅱ), and paddy-cotton (cropping system Ⅲ). Most of the sample farmers belonged to marginal and small farm groups in all the selected cropping systems under study. The yield in cropping system I was estimated to be 64.35 qt/ha (rabi paddy) and 23.63 qt/ha in cropping system I, followed by kharif paddy (62.02 qt/ha) and rabi paddy (65.08qt/ha) in cropping system II and paddy (63.09 qt/ha) & cotton (32.09 qt/ha) in cropping system III. The gross returns were recorded maximum in the Cropping system Ⅲ, followed by the cropping system Ⅰ and then cropping system Ⅱ. Thus, the sample farmer realized a comparatively high net income in cropping system III, followed by cropping systems I and II. The output-input ratio was revealed to be highest under the cropping system Ⅲ, followed by the cropping system Ⅰ & cropping system Ⅱ. Hence, it may be opined that the paddy-cotton cropping system would be more profitable than the paddy-groundnut and paddy-paddy cropping systems. Factors affecting sustainability indicated that variables such as gross income per acre, returns to cost ratio, fertilizer productivity, and cost of ecosystem-friendly inputs to total cost of cultivation were favourably significant at the 1% probability level in cropping system III.

Thus, it may be concluded that the paddy-cotton system was found to be the most profitable and sustainable in the study area, which may be adopted by the farming community to safeguard the soil-water quality as well as retard environmental degradation and also to enhance the profitability of farmers in the study area.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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