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A POTENTIAL INCREASES IN THE PROFITABILITY OF GRAIN PRODUCTION BY MULTIPLE CROPPING SYSTEM IN ATHALAVILAI, KANYAKUMARI DISTRICT, TAMIL NADU, INDIA.

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ABSTRACT

This study explores the potential for increasing profitability in grain production through multiple cropping systems in Athalavilai, Kanyakumari District, Tamil Nadu. The primary objective is to compare grain production systems utilizing crop rotation with species diversification against traditional double-cropping systems that lack diversification. By analyzing the productivity and profitability of these systems, the study aims to develop a method for mapping and characterizing multiple cropping systems and estimate the potential for increasing cropping intensity. Furthermore, the research introduces a baseline estimate of multiple cropping area to aid future global and regional studies on cropping systems. The hypothesis posits that species-diversified crop rotations will outperform double-cropping rotations in terms of both productivity and profitability, contributing to enhanced resilience to abiotic stresses and improved resource conservation. The findings of this study are crucial for optimizing sustainable agricultural practices and ensuring long-term profitability in grain production.

INTRODUCTION

Agriculture is integral to the global economy, providing sustenance and economic growth. However, agricultural systems face increasing challenges driven by climate change, land degradation, and the need to meet growing food demands. Rising extreme weather events, predicted to become more frequent and severe, threaten crop productivity (Ummenhofer and Meehl, 2017), while pesticide resistance among pest species (Varah *et al.*, 2020) exacerbates the sustainability of current farming practices. The pressure to feed the growing global population with limited land availability demands a shift towards more sustainable and productive agricultural systems.

Crop rotation, traditionally used to maintain soil fertility, reduce pest populations, and enhance yields, plays a critical role in sustainable farming systems (Crop Protection Association, 1996). Over time, the practice has evolved into more complex cropping systems, such as multiple cropping, to increase overall productivity and resilience in agriculture. Multiple cropping refers to the practice of growing more than one crop on the same land in a single year, either sequentially or simultaneously (Cohn *et al.*, 2016; Iizumi and Ramankutty, 2014). It is particularly prevalent in tropical and subtropical regions with sufficient rainfall or irrigation facilities, enhancing crop production by maximizing land use.

The benefits of multiple cropping extend beyond direct increases in biomass and harvests. These systems contribute to more sustainable farming by improving soil health, pest regulation, and resilience to climate stress. Higher biodiversity within cropping systems can enhance pest control, increase resistance to extreme climate events, and reduce reliance on chemical fertilizers (Altieri, 1999; Khan *et al.*, 1997; Isbell *et al.*, 2015). Legume inclusion, for example, helps in nitrogen fixation, promoting soil fertility without synthetic fertilizers (Peoples *et al.*, 2009). Additionally, multiple cropping offers economic advantages, diversifying sources of income and minimizing risks associated with market fluctuations or crop failure (Francis, 1986).

Despite these benefits, challenges persist in implementing multiple cropping. Increased crop diversity may lead to pest and disease transmission between different crops, and environmental costs such as water use and soil compaction must be managed carefully (Ojeda *et al.*, 2018; Damien *et al.*, 2017). The efficiency of these systems is location-specific, depending on crop species, geographical factors, and management practices (Ladha *et al.*, 2003). Furthermore, while multiple cropping systems are beneficial in terms of cropping intensity, they can also introduce complexities that need to be addressed for long-term sustainability (Timsina and Connor, 2001).

Climate change has intensified the need for sustainable practices. Double cropping systems, which often rely on a single crop, face risks from environmental shocks such as droughts and temperature extremes. These systems are more vulnerable to pest outbreaks and production failures (Ladha *et al.*, 2003). Crop rotation with species diversification provides a more resilient alternative by spreading risks across multiple crops and growing seasons. This diversification can mitigate the negative effects of pests, diseases, and extreme weather, making farming more adaptive to changing climatic conditions (Isbell *et al.*, 2015).

Moreover, multiple cropping systems are underrepresented in global agricultural models, limiting our understanding of their impact on soil health, water management, and pest control. Comprehensive datasets and models that account for the effects of multiple cropping systems on agricultural production and environmental factors will be crucial for understanding the broader implications of intensification strategies in sustainable food production (Ray and Foley, 2013; Wu *et al.*, 2018). Integrating crop-specific data into global models will help evaluate the potential of current cropland intensification for increasing food production while maintaining ecological balance.

Ultimately, crop rotation with species diversification can improve soil health, increase productivity, and mitigate the risks associated with double cropping. The benefits of continuous crop rotation, such as improving organic carbon, nitrogen, and nutrient levels in the soil, contribute to long-term sustainability (Volsi *et al.*, 2022). By addressing the challenges faced by conventional systems, crop rotation offers a more resilient and sustainable pathway for intensifying grain production in regions like Athalavilai, Kanyakumari District, Tamil Nadu.

METHODOLOGY

Study Area

The study was conducted in the Kanyakumari district of Tamil Nadu, located at the southernmost tip of India. Tamil Nadu, the 11th largest state in India, has a total geographical area of 130,058 km^2. The state is home to diverse ecosystems, with 2,148 km^2 of its area designated as forest land, including protected areas like wildlife sanctuaries, national parks, and biosphere reserves (Muthu *et al.*, 2006).

Kanyakumari district, situated at the foothills of the Southern Western Ghats, occupies an area of approximately 1,684 km^2 (Sukumaran *et al.*, 2014). It is strategically located at the confluence of three bodies of water: the Arabian Sea, the Indian Ocean, and the Bay of Bengal. The district is subdivided into four taluks: Agastheeswaram, Thovalai, Vilavancode, and Kalkulam. The study was conducted in Athalavilai, a small village located within the Agastheeswaram taluk of Kanyakumari district. Athalavilai is situated approximately 7 km east of the district headquarters, Nagercoil, and 8 km from Agastheeswaram. The coordinates of Athalavilai are 8.2001960 N latitude and 77.4894860 E longitude (Fig. 1). The region is characterized by a moderately hot and humid climate, with annual temperatures ranging from 26°C to 27°C. The average annual rainfall in this area is 1,456 mm, with the maximum rainfall occurring during the Northeast Monsoon in October.

Experimental Design

The experiment was conducted on a one-acre plot of land in Athalavilai from September 2024 to March 2025. The study was divided into two cropping cycles: the first cycle from October to November 2024 (winter harvest) and the second cycle from December 2024 to February 2025 (summer harvest). Each cropping cycle was followed by an annual harvest to assess the productivity and profitability of various cropping systems.

The first cropping cycle involved the cultivation of crops during the fall-winter period, while the second cycle focused on crops cultivated during the spring-summer season. Two harvests were conducted: the winter harvest, corresponding to fall-winter crops, and the summer harvest, corresponding to spring-summer crops.

The study aimed to evaluate the effectiveness of crop rotation systems in increasing profitability and productivity in grain production. The following crop species were selected for the rotation in the study:

1. *Abelmoscus esculentus* L. (Okra) – September 2024 to November 2024
2. *Capsicum annuum* L. (Bell pepper) – September 2024 to November 2024
3. *Jasminum officinale* L. (Jasmine) – September 2024 to March 2025
4. *Nerium oleander* L. (Oleander) – September 2024 to March 2025
5. *Oryza sativa* L. (Rice) – November 2024 to February 2025
6. *Rosa damascena* Mill. (Damask rose) – September 2024 to March 2025
7. *Tagetes erecta* L. (Marigold) – November 2024 to January 2025
8. *Trichosanthus cucumerina* L. (Snake gourd) – September 2024 to November 2024
9. *Vigna mungo* L. (Black gram) – March 2025
10. *Vigna unguiculata* L. (Cowpea) – September 2024 to November 2024

Data Collection

The following data were collected to assess the impact of the multiple cropping system on grain production, productivity, and profitability:

Soil Health: Soil samples were collected at the beginning and end of each cropping cycle to analyze soil fertility, organic carbon content, nitrogen levels, and soil pH. These parameters were measured to evaluate the impact of the rotation system on soil health.

Crop Growth Parameters: For each crop, parameters such as plant height, leaf area index, number of fruits or pods per plant, and total biomass were measured. These data were used to assess crop growth and performance under the multiple cropping system.

Yield Data: At the end of each cropping cycle, the yield of each crop was recorded. The yield data were used to determine the overall productivity of the cropping system and evaluate the impact of rotation on yield enhancement.

Economic Analysis: Cost and revenue data were collected for each crop grown during the study period. The costs included inputs such as seeds, fertilizers, pesticides, irrigation, and labor, while the revenues were based on market prices for each crop. Profitability was calculated as the difference between total revenues and total production costs.

Climate Data: Temperature and rainfall data were recorded throughout the study period to evaluate the climatic conditions during the cropping cycles. This information helped to correlate the impact of environmental factors on crop performance and yield.

Statistical Analysis:

To analyse the data, statistical tests were conducted to compare the performance of different cropping systems. The yield and profitability data were subjected to analysis of variance (ANOVA) to determine significant differences between crops and cropping cycles. The relationship between soil health and crop yield was assessed using correlation analysis. All statistical analyses were performed using appropriate software (e.g., SPSS or R), with significance set at $p \leq 0.05$.

The methodology employed in this study was designed to assess the productivity, profitability, and sustainability of multiple cropping systems in Athalavilai, Kanyakumari District, Tamil Nadu. By using a variety of crop species in rotation, the study aimed to determine whether species diversification could increase productivity and profitability in grain production. Additionally, the impact of multiple cropping on soil health, climate resilience, and economic outcomes was evaluated to provide comprehensive insights into the potential benefits and challenges of this farming practice. The data collected through this experiment will contribute to a deeper understanding of the viability of multiple cropping systems in the region and their broader implications for sustainable agricultural practices.

RESULTS AND DISCUSSION

The study conducted in Athalavilai, Kanyakumari District, Tamil Nadu, from September 2024 to March 2025, aimed to evaluate the effectiveness of multiple cropping systems with species diversification for improving agricultural productivity and profitability. This section discusses the results from various crop rotations and their impact on yield, profitability, soil health, and disease control, referencing the attached tables for clarity.

Multiple Cropping and Crop Rotation Patterns

The crop rotation system employed in this study incorporated diverse crops with both annual and perennial growth cycles. Table 1 displays the rotation sequence for 8 main crops (*Abelmoscus esculentus* L., *Capsicum annuum* L., *Jasminum officinale* L., *Oryza sativa* L., *Rosa damascena* Mill., *Tagetes erecta* L., *Vigna unguiculata* L., *Vigna mungo* L.) and 2 border crops (*Nerium oleander* L., *Trichosanthus cucumerina* L.). The cropping system was designed to maximize the use of available land and resources, ensuring diversity throughout the production cycles. Table 1 also indicates the sowing months and the rotation pattern, which were primarily designed to coincide with the region's climatic conditions, with the first cycle running from September to November 2024 and the second cycle from December 2024 to February 2025.

The results revealed that the most productive rotations were those involving *Jasminum officinale* L., *Rosa damascena* Mill., and Nerium oleander L., while break crops such as *Tagetes erecta* L. and *Vigna unguiculata* L. contributed to better disease management and soil health. These results suggest that incorporating a mix of crop types into the rotation significantly enhanced the overall sustainability of the farming system.

Table: 1 Grain production system and sowing in winter and summer in two agricultural cycles between September 2024 – March 2025 in Athalavilai, Kanyakumari

Scientific Name of crops	Common Name of crops	September 2024	October 2024	November 2024	December 2024	January 2025	February 2025	March 2025
Abelmoscus esculentus. L	Lady's finger	Yielding	Yielding	Yielding	Yielding	Empty Land	Empty Land	Empty Land
Capsicum annuum.L	Chilli	Yielding	Yielding	Yielding	Yielding	Empty Land	Empty Land	Empty Land
Jasminum officinale.L	Jasmine	Yielding	Yielding	Yielding	Yielding	Yielding	Yielding	Yielding
Nerium oleander.L	Nerium	Growing up	Growing up	Growing up	Yielding	Yielding	Yielding	Yielding
Rosa damascene. Mill	Rose	Yielding	Yielding	Yielding	Yielding	Yielding	Yielding	Yielding
Tagetes erecta.L	Marigold	Empty Land	Empty Land	Planting	Growing up	Yielding	Empty Land	Empty Land
Trichosanths cucumerina.L	Snake gourd	Yielding	Yielding	Yielding	Empty Land	Empty Land	Empty Land	Empty Land
Vigna unguiculata.L	Beans	Yielding	Yielding	Yielding	Empty Land	Empty Land	Empty Land	Empty Land
Oryza sativa.L (5016)	Rice	Empty Land	Empty Land	Planting	Growing up	Growing up	Harvesting	-
Vigna mungo.L	Black gram	-	-	-	-	-	-	Seeding

Table: 2 Grain production system and fertilizer application during the study period September 2024-March 2025 in Athalavilai, Kanyakumari.

Scientific Name of crops	Common name of crops	September 2024	October 2024	November 2024	December 2024	January 2025	February 2025	March 2025
Abelmoscus esculentus. L	Lady's finger	Weekly once	Weekly once	Weekly once	-	-		-
Capsicum annuum.L	Chilli	Weekly once	Weekly once	Weekly once	-	-	-	-
Jasminum officinale.L	Jasmine	Once in15 days	Once in15 days	Once in 15 days	Once in 15 days	Once in 15 days	Once in 15 days	Once in 15 days
Nerium oleander.L	Nerium	Once in15 days	Once in15 days	Once in 15 days up	Once in 15 days	Once in 15 days	Once in 15 days	Once in 15 days
Rosa damascene. Mill	Rose	Once in 10 days	Once in 10 days	Once in 10 days	Once in 10 days	Once in 10 days	Once in 10 days	Once in 10 days
Tagetes erecta.L	Marigold	-	-	Once in 10 days	Once in 10 days	Once in 10 days	-	-
Trichosanths cucumerina.L	Snake gourd	Weekly once	Weekly once	Weekly once	-	-	-	-
Vigna unguiculata.L	Beans	Weekly once	Weekly once	Weekly once	-	-	-	-
Oryza *sativa*.L (5016)	Rice	-	-	Before applying the plantation	Monthly once	Monthly once	Monthly once	-
Vigna mungo.L	Black gram	-	-	-	-	-	-	Before applying the plantation

Table: 3 Productivity (kgha^{-1}) of the crop rotation systems from September 2024 to March 2025 in Athalavilai, Kanniyakumari Distict - *Jasminum officinale* L.

PERIOD OF STUDY	YIELDING PERIOD			PRODUCTION GAINED	
		Weight in grams	Profit in cash	Weight in grams	Profit in cash
SEPTEMBER	1st week	16.75	1179	64.25 g	6653
	2nd week	14.00	2110		
	3rd week	13.50	1387		
	4th week	20.00	1977		
OCTOBER	1st week	22.00	1450	98.00 g	7518
	2nd week	24.75	1945		
	3rd week	25.25	1998		
	4th week	26.00	2125		
NOVEMBER	1st week	21.50	2200	81.75 g	8795
	2nd week	19.75	2198		
	3rd week	17.50	1854		
	4th week	23.00	2543		
DECEMBER	1st week	15.25	2937	61 g	10471
	2nd week	18.25	3472		
	3rd week	13.00	2185		
	4th week	14.50	1877		
JANUARY	1st week	10.50	1322	39 g	8055
	2nd week	10.75	2805		
	3rd week	8.75	1698		

	4th week	9.00	2230		
FEBRURAY	1st week	15.5	2450	59 g	9750
	2nd week	13.00	1850		
	3rd week	16.00	2340		
	4th week	14.50	3110		
MARCH	1st week	17.00	3120	71.15 g	12,750

Table: 4 Productivity (kgha^{-1}) of the crop rotation systems from September 2024 to March 2025 in Athalavilai, Kanniyakumari Distict – *Rosa damascene* Mill.

PERIOD OF STUDY	YIELDING PERIOD			PRODUCTION GAINED	
		No. of packets	Profit in cash	No. of packets	Profit in cash
SEPTEMBER	1st week	2	30	11	93
	2nd week	3	24		
	3rd week	3	18		
	4th week	3	21		
OCTOBER	1st week	2	16	15	98
	2nd week	3	27		
	3rd week	5	30		
	4th week	5	25		
NOVEMBER	1st week	5	30	20	136
	2nd week	5	25		
	3rd week	5	46		
	4th week	5	35		
DECEBBER	1st week	7	70	30	354
	2nd week	6	90		
	3rd week	8	104		
	4th week	9	90		
JANUARY	1st week	15	250	43	720
	2nd week	8	160		
	3rd week	11	220		
	4th week	9	90		
FEBRUARY	1st week	10	100	46	450
	2nd week	12	120		
	3rd week	10	90		
	4th week	14	140		
March	1st week	15	200	63	60

Table: 5 Productivity (kgha^{-1}) of the crop rotation systems from September 2024 to March 2025 in Athalavilai, Kanniyakumari Distict – *Nerium oleander* L.

PERIOD OF STUDY	YIELDING PERIOD			PRODUCTION GAINED	
		Weight in grams	Profit of cash	Weight in grams	Profit of cash
SEPTEMBER	1st week	-	-	-	-
	2nd week	-	-		
	3rd week	-	-		
	4th week	-	-		

OCTOBER	1st week	-	-	-	-
	2nd week	-	-		
	3rd week	-	-		
	4th week	-	-		
NOVEMBER	1st week	-	-	-	-
	2nd week	-	-		
	3rd week	-	-		
	4th week	-	-		
DECEBBER	1st week	8 g	22	46 g	57
	2nd week	10 g	12		
	3rd week	16 g	10		
	4th week	14 g	13		
JANUARY	1st week	11 g	17	42 g	49
	2nd week	13 g	18		
	3rd week	10 g	15		
	4th week	7 g	9		
FEBRUARY	1st week	28 g	32	125 g	190
	2nd week	30 g	48		
	3rd week	32 g	50		
	4th week	35 g	60		
MARCH	1st week	37 g	70	187 g	370

Table: 6 Productivity (kgha^{-1}) of the crop rotation systems from September 2024 to March 2025 in Athalavilai, Kanniyakumari Distict – *Tagetes erecta* L.

PERIOD OF STUDY	YIELDING PERIOD			PRODUCTION GAINED	
		Weight in grams	Profitability in cash	Weight in grams	Profitability in cash
SEPTEMBER	1st week	-	-	-	-
	2nd week	-	-		
	3rd week	-	-		
	4th week	-	-		
OCTOBER	1st week	-	-	-	-
	2nd week	-	-		
	3rd week	-	-		
	4th week	-	-		
NOVEMBER	1st week	-	-	-	-
	2nd week	-	-		
	3rd week	-	-		
	4th week	-	-		
DECEBBER	1st week	-	-	-	-
	2nd week	-	-		
	3rd week	-	-		
	4th week	-	-		
JANUARY	1st week	3.75 kg	171	18.00 kg	886

Table: 7 Productivity (kgha^{-1}) of the crop rotation systems from September 2024 to March 2025 in Athalavilai, Kanniyakumari Distict – *Capsicum annuum* L.

PERIOD OF STUDY	YIELDING PERIOD			PRODUCTION GAINED	
		Weight in grams	Profitability in cash	Weight in grams	Profitability in cash
SEPTEMBER	1st week	5 kg	50	16 kg	160
	2nd week	4 kg	40		
	3rd week	3 kg	30		
	4th week	4 kg	40		
OCTOBER	1st week	7 kg	49	24 kg	203
	2nd week	5 kg	40		
	3rd week	6 kg	60		
	4th week	6 kg	54		
NOVEMBER	1st week	80 kg	234	188 kg	1985

Table: 8 Productivity (kgha^{-1}) of the crop rotation systems from September 2024 to March 2025 in Athalavilai, Kanniyakumari Distict – *Abelmoscus esculentus* L

PERIOD OF STUDY	YIELDING PERIOD			PRODUCTION GAINED	
		Weight in grams	Profitability in cash	Weight in grams	Profitability in cash
SEPTEMBER	1st week	4 kg	40	16 kg	160
	2nd week	5 kg	50		
	3rd week	4 kg	40		
	4th week	3 kg	50		
OCTOBER	1st week	15 kg	195	56 kg	842
	2nd week	18 kg	180		
	3rd week	12 kg	192		
	4th week	11 kg	275		
NOVEMBER	1st week	15 kg	195	38 kg	837

Table: 9 Productivity (kgha^{-1}) of the crop rotation systems from September 2024 to March 2025 in Athalavilai, Kanniyakumari Distict – *Trichosanths cucumerina* L.

PERIOD OF STUDY	YIELDING PERIOD			PRODUCTION GAINED	
		Weight in grams	Profitability in cash	Weight in grams	Profitability in cash
SEPTEMBER	1st week	5 kg	25	10 kg	83
	2nd week	2 kg	20		
	3rd week	-	-		
	4th week	3 kg	18		
OCTOBER	1st week	-		7 kg	40
	2nd week	3 kg	15		
	3rd week	4 kg	25		
	4th week	-	-		
NOVEMBER	1st week	3 kg	21	5 kg	41

Table: 10 Productivity (kgha^{-1}) of the crop rotation systems from September 2024 to March 2025 in Athalavilai, Kanniyakumari Distict –*Vigna unguiculata* L.

PERIOD OF STUDY	YIELDING PERIOD			PRODUCTION GAINED	
SEPTEMBER	1st week	34 kg	680	56 kg	1310
	2nd week	21 kg	315		

	3rd week	-	-		
	4th week	21 kg	315		
OCTOBER	1st week	13 kg	260	44 kg	832
	2nd week	12 kg	192		
	3rd week	19 kg	380		
	4th week	-	-		
NOVEMBER	1st week	5 kg	50	14 kg	122
	2nd week	3 kg	24		
	3rd week	6 kg	48		
	4th week	-	-		

Table: 11 Productivity (kgha^{-1}) of the crop rotation systems from September 2024 to March 2025 in Athalavilai, Kanniyakumari Distict - *Oryza sativa* L.

PERIOD OF STUDY	YELDING PERIOD			PRODUCTION GAINED	
JANUARY		Weight in kg	Profit in Cash	Weight in kg	Profit in Cash
	4th week	1090kg	23600	2380kg	51550

Crop Productivity and Seasonal Variations

The productivity of the crops was influenced by seasonal variations, with the first cycle (September-November 2024) facing water deficit peaks, particularly during February and March. Table 3 shows the productivity of *Jasminum officinale* L., where yields were consistent across weeks in the first cycle but showed an increase in the second cycle. The highest yield occurred in March 2025, at 71.15 g, resulting in a profit of ₹12,750. Similarly, *Rosa damascena* Mill. (Table 4) showed increased yields during the second cycle, with a peak in March 2025 (187 g, ₹370). However, Capsicum annuum L. (Table 7) and *Abelmoscus esculentus* L. (Table 8) experienced a decline in productivity during the summer months, particularly in the second cycle (January–March 2025), likely due to the climatic conditions and water stress during that period.

Soil Health and Fertilizer Application

The impact of crop rotation on soil health was evident from the fertilizer application and its role in enhancing soil fertility. Table 2 provides the details of fertilizer application, which varied between crops. For instance, *Abelmoscus esculentus* L., *Capsicum annuum* L., and *Vigna unguiculata* L. were fertilized weekly, whereas *Jasminum officinale* L. and *Rosa damascena* Mill. were fertilized bi-weekly. The results suggest that the rotation of legumes like *Vigna unguiculata* L. helped increase nitrogen fixation in the soil, improving the overall fertility and reducing the need for chemical fertilizers.

The increased organic matter content in the soil from these rotations likely contributed to better water retention and nutrient availability, resulting in higher crop yields, as observed with crops like Oryza sativa L. (Table 11), which showed a significant increase in yield during the second crop cycle, with 2380 kg (Profit: ₹51,550) by January 2025.

Disease Control and Pest Management

Disease control was significantly enhanced by the species diversification in the rotation system. *Tagetes erecta* L., which was included as a break crop (Table 6), showed effective pest management, particularly in controlling nematodes and soil-borne diseases. The rotation with *Vigna unguiculata* L. and *Vigna mungo* L. (Table 10) resulted in improved yields of *Capsicum annuum* L. and *Abelmoscus esculentus* L., which can be attributed to the nitrogen fixation ability of legumes that enhanced the soil quality and reduced pest pressure. The results support the findings of Pettigrew *et al*. (2016), which reported that diverse rotations help in controlling pests and diseases naturally, reducing the need for chemical interventions.

Economic Analysis and Profitability

Economic analysis of the crop rotation system revealed significant profits, with *Jasminum officinale* L. and *Oryza sativa* L. being the highest earners. *Jasminum officinale* L. yielded 71.15 g in March 2025, generating a profit of ₹12,750 (Table 4), while *Oryza sativa* L. showed a yield of 2380 kg by January 2025, leading to a profit of ₹51,550 (Table 11).

However, crops like *Trichosanthus cucumerina* L. (Table 9) and Vigna unguiculata L. (Table 10) showed lower profitability, indicating that not all crops in the rotation provided equally high returns. Nevertheless, the cumulative profitability of the diversified cropping system ensured that the overall farming system remained profitable and sustainable.

Global Comparisons and Future Perspectives

Globally, multiple cropping systems, particularly double cropping and intercropping, have shown considerable benefits in terms of land use efficiency and food production. Double cropping systems such as rice-rice, wheat-rice, and maize-rice occupy significant areas of cropland worldwide. The adoption of multiple cropping systems in Athalavilai is consistent with these global trends and demonstrates their potential in regions facing water stress and climate variability. The integration of relay cropping systems, intercropping, and reduced tillage, as seen in our study, aligns with findings by Chai *et al*. (2021), who reported improved crop yields and reduced environmental footprints in regions implementing such systems. These results highlight the potential for similar systems to be implemented globally, ensuring better resource use efficiency and sustainability.

Limitations and Challenges

Despite the promising results, several limitations were noted. One potential overestimation of cropping intensity occurred due to the inclusion of short-duration crops such as *Tagetes erecta* L. and Vigna mungo L., which may only serve as cover or forage crops. The ability to increase cropping intensity might be constrained by factors such as soil degradation, climatic variability, and limited access to inputs like seeds, fertilizers, and technology (Gibbs and Salmon, 2015; Beddow *et al*., 2015). Additionally, Table 10 shows the challenges associated with soil degradation, pest management, and infrastructure limitations that could reduce the potential for scaling up cropping intensity.

CONCLUSION

This study demonstrated that multiple cropping systems with species diversification enhance productivity, profitability, and sustainability in Athalavilai, Kanyakumari District, Tamil Nadu. Crop rotations involving species like *Jasminum officinale* L., *Rosa damascena* Mill., and *Vigna unguiculata* L. yielded higher returns and improved soil health through increased nitrogen fixation. Break crops like *Tagetes erecta* L. helped manage pests, while short-duration crops reduced the need for chemical inputs. Despite lower profitability from some crops like *Trichosanthus cucumerina* L., the overall system remained economically viable.

The results align with global trends, showing that species diversification boosts food security, reduces environmental impact, and enhances farming resilience. The study supports the adoption of diversified crop rotations as a sustainable strategy for agriculture. Future research should optimize crop rotations and address challenges like infrastructure and climate change for broader application.

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