



Performance of cotton (*Gossypium* spp.) as a relay crop in banana (*Musa × paradisiaca*) cropping system: A way to sustainable crop diversification in the Cauvery Delta region, Tamil Nadu

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Received: 04 November 2024; Accepted: 28 August 2026

ABSTRACT

A field study was carried out to assess the effectiveness of relay cropping of cotton (*Gossypium* spp. L.) under banana (*Musa × paradisiaca* L.) cropping systems in improving crop productivity and farmers' income during 2020–21 and 2021–22 by Krishi Vigyan Kendra, Sirugamani, Tiruchirappalli, Tamil Nadu. The field experiment was laid out in a randomised block design with three replications having six treatments, viz. T₁, Banana sole crop; T₂, Cotton sole crop; T₃, Cotton two-rows without fertiliser; T₄, Cotton four-rows without fertiliser; T₅, Cotton two-rows with fertiliser; and T₆, Cotton four-rows with fertiliser. Among the cotton crops, T₂ and T₅ yielded highest with 18.57 q/ha and 17.87 q/ha, respectively. Compared to the banana yield obtained from the relay cropping system, a higher yield was obtained from banana sole crops (385.1 q/ha), followed by T₅ (381.7 q/ha). The banana–cotton relay system without fertiliser showed the highest benefit-cost ratio (5.01). Further, the two-row and four-row systems with and without fertiliser application, respectively showed higher land use efficiencies (126.9% and 126.0%, respectively) compared to the sole crop. Production efficiency of 87.17% was recorded for the T₄ application, followed by T₅ (86.68%). The results indicated banana and cotton yield losses of 1.06–2.12% and 4.76–15.85%, respectively, compared to sole crops. Despite these losses, the cropping system maintained profitability with a land equivalent ratio of more than 1.0. Thus, cotton as a relay crop produced the highest economic returns using available land and nutrient resources. Therefore, the banana–cotton relay cropping system may be recommended for wetland conditions to enhance both banana and cotton productivity.

Keywords: Banana–cotton, Farm income, Land use efficiency, Sustainable agriculture, System productivity

Relay cropping is the most common intercropping system, where two crops are planted sequentially in the same field before harvesting the first crop. The purpose of relay cropping is to make efficient use of natural resources like land, labour, and water, to increase yields and profits, improve soil quality, enhance land equivalent ratio, and control weed infestations without expanding farmland

(Ocimati *et al.* 2019, Lamichhane *et al.* 2023). Success in relay cropping depends on the climate, type of crop, and planting time (Gesch *et al.* 2023a). Banana (*Musa × paradisiaca* L.) is the second most important fruit crop grown in the Cauvery Delta region due to the suitability of soil and climate. Among all countries, India produces most banana (32,454 000 MT) with 26.75% of the global production. Tamil Nadu ranks fourth in banana production (3,895.64 000 MT), accounting for 10.41% of the country's total production, contributing approximately ₹10 lakh crore to India's economy (Meenakshi and Manikonda 2022). In Tamil Nadu, Tiruchirappalli ranks fifth in terms of area (7,002 ha) under cultivation and production and third in productivity (Karthikeyan *et al.* 2021).

India is also the largest producer of cotton (*Gossypium* spp. L.), contributing 24% of the global production. Cotton has been traditionally grown as an intercrop and as a relay crop, offering several advantages including its high economic value, low water and nutrient requirements,

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compact canopy with dwarf varieties, easy cultivation, low risk of failure, synergistic growth with other crops, reduced pest attack, and better adaptation for marginal areas, etc. Given the significant economic importance of both banana and cotton in India, especially in regions like Tamil Nadu, combining the two crops through relay cropping could be a game changer. To explore these potential benefits, a study was carried out in the wetland delta region of the Cauvery River to analyse the performance of cotton as a relay crop in banana cultivation.

MATERIALS AND METHODS

The present investigation was conducted during 2020–21 and 2021–22 at Krishi Vigyan Kendra, Sirugamani, Tiruchirappalli (10°85'N, 75°55'E), Tamil Nadu. In Tiruchirappalli district, it is estimated that 1,85,193 ha of land have been cultivated, out of which 1,02,799 ha are under irrigation and 82,394 ha are under rainfed cultivation. The Cauvery River serves as one of the most important sources of irrigation in the region. An experimental farm was established in clay loam soil having medium organic carbon content (0.54%), with a pH value of 8.1 and an EC of 0.81 dS/m. The soil's fertility level is medium for available nitrogen (360.8 kg/ha) and available phosphorus (13.9 kg/ha) and high for available potassium (428.7 kg/ha). An average annual rainfall of 665 mm was recorded in 2020 and 976 mm in 2021. There were significant differences between the maximum and minimum relative humidity levels, with 84.6% in December and 56.4% in June 2020, and 85.6% in January and 56.6% in June 2021.

The experiment consisted of six treatments which included T₁, Banana sole crop; T₂, Cotton sole crop; T₃, Cotton two-rows without fertiliser; T₄, Cotton four-rows without fertiliser; T₅, Cotton two-rows with fertiliser; and T₆, Cotton four-rows with fertiliser. The field experiment was laid out in a randomised block design with three replications. Banana suckers (Nendran variety) were planted in April 2020 and 2021 at a spacing of 1.8 m × 1.8 m with 1,200 suckers. The cotton variety 'MCU 5' was planted as a monoculture and intercropped in standing banana plants with spacing of 0.90 m × 0.45 m for the two-row system and 0.60 m × 0.45 m for the four-row system. Cotton in the standing banana was planted in February 2020 and 2021. Banana was fertilised with nitrogen (N), phosphorus (P), and potassium (K) at 150:90:300 kg/ha, respectively. Nitrogen and potassium were applied in three splits on the 3rd, 5th and 7th month, while phosphorus was applied in the 3rd month after planting. The cotton crop was fertilised with N, P, and K at 82:40:40 kg/ha. Fifty percent of N and K, along with the full dose of P were applied as basal, and the remaining half dose of N and K was applied at 45 days after sowing.

Parameters recorded: The land equivalent ratio (Willey 1985), benefit-cost ratio, land use efficiency (Schiavina *et al.* 2019), production efficiency, and profitability were calculated. The formulae for calculating various metrics are given below.

$$\text{Land equivalent ratio (LER)} = \frac{Y_{ci}}{Y_{cs}} + \frac{Y_{bi}}{Y_{bs}}$$

Where Y_{ci}, Y_{cs}, Y_{bi}, and Y_{bs}, Yields of intercropped and sole cotton, as well as the banana yields of intercropped and sole banana, respectively.

$$\text{Land use efficiency (LUE) (\%)} = \frac{D_1 + D_2}{365} \times 100$$

Where D₁ and D₂, Number of cropping days for the first and second crops in the cropping system, respectively.

$$\text{Production efficiency (PE) (\%)} = \frac{Y_1 + Y_2}{D_1 + D_2} \times 100$$

Where Y₁ and D₁, Yield and duration of the first crop; Y₂ and D₂, Yield and duration of the second crop, respectively (Kamrozzaman *et al.* 2015).

$$\text{Profitability (₹/day/ha)} = \frac{\text{Total net income of cropping system}}{\text{Total cropping duration}}$$

RESULTS AND DISCUSSION

Crop yield and profit: The results of this study revealed that cotton grown as a relay crop had a significant impact on banana yield in 2020–21 and 2021–22 (Table 1). In all treatment combinations, banana yields differed significantly between relay intercropping and non-relay intercropping systems. Among the cotton crops, those grown as sole crops (T₂) and in the two-row system with the fertiliser application (T₅) yielded more with 18.57 q/ha and 17.87 q/ha, respectively. Cotton in the four-row system without fertiliser treatment (T₄) yielded the least (14.71 q/ha). Optimum crop spacing provides adequate light penetration, aeration, and nutrient availability, reducing crop competition among plants and enhancing photosynthetic efficiency, which ultimately improves crop yield. Similar trends were observed by Sandhu *et al.* (2021) in tomato and bell pepper relay cropping system. Compared to the banana yield measured under the relay cropping system, a higher yield was obtained from banana sole crops (T₁) (385.1 q/ha), followed by banana with cotton in the two-row systems with fertiliser applications (T₅; 381.7 q/ha). A similar result was observed by Singh (2023), who found that paddy–mustard + berseem produced the greatest equivalent yield (35–62%) and system productivity (4.86 t/ha), while green gram–mustard + berseem received the maximum additional net return (₹46,300/ha). Among relay intercropping treatments, there was a significant difference in cotton yield. The reduction in cotton yield under this system was found to be 4.76–15.85% lower than that of sole crops. This is caused by the competition for nutrient uptake and sunlight between the two crops during their overlapping growth period (Gesch *et al.* 2023b).

In the banana–cotton relay system, net income and benefit-cost ratios were also computed. The frequency of cotton production and farmers' income is influenced by using cotton as a relay crop. A similar relationship exists

between the number of rows and the application of fertiliser in different systems. This might be due to the potential for high yields from individual crops and their compatibility with the main crops. Crop compatibility enhances yield by matching plants that support one another's resource utilisation, control pests naturally, and enrich the soil. Additionally, the benefit-cost ratio of the banana–cotton relay cropping system significantly outperforms the sole cropping system, yielding higher returns compared to the sole cropping system. According to the results, the relay system contributed an additional ₹59,445/ha farm income, with a benefit-cost ratio of 5.01. The T_5 treatment had a higher net income ₹12,61,838/ha compared to the sole cropping. In contrast, T_4 recorded a net income of ₹12,37,245/ha (Table 2). Cotton planted in a four-row yielded less compared to the two-row system. This is because the four-row system has a higher population density, which affects yield. There is a significant correlation between population density and yield, with deviations from optimal density resulting in decreased yields. Increased planting density leads to greater competition for light among individual plants. These findings are supported by Liu *et al.* (2022) in a maize–green manure relay cropping system.

In comparison to monoculture, the relay cropping system has a greater LER indicating increased land use efficiency (Fig. 1). The land equivalent ratio for the banana–cotton relay-cropping system ranged from 1.74–1.95. Relay-cropping systems with LERs greater than 1 are considered more efficient in land use compared to monocultures (Raza *et al.* 2023, Suntari *et al.* 2023). Similar reports have been suggested by Sandhu *et al.* (2020) in eggplant and strawberry relay cropping. For instance, relay intercropping of short season cotton before the wheat harvest could potentially increase cotton yields and benefits in river basins (Wang *et al.* 2021). However, despite the benefits, reduced biomass accumulation in relay cropping systems may slightly decrease yields, resulting in lower overall production benefits. But the relay cropping system has doubled the LER. The same results on the increased land equivalent ratios of 1.99 and 1.8 were obtained by Islam *et al.* (2023) in maize–mukhikachu (colocasia) and Sahuri *et al.* (2023)

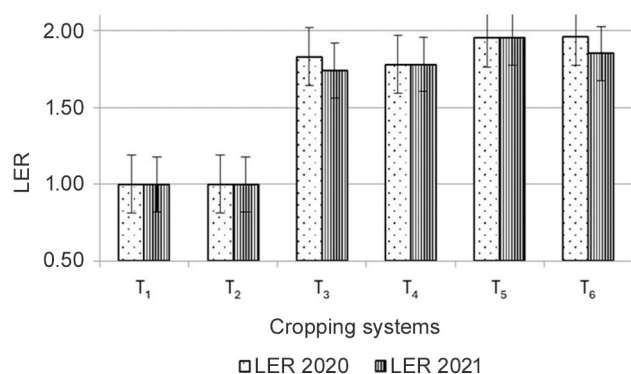


Fig. 1 Effect of cotton as relay crop with banana cultivation on land equivalent ratio (LER).

Treatment details are given under Materials and Methods.

Table 1 Effect of relay cropping system on yield and economics of cotton and banana

Treatment	Cotton						Banana											
	Yield (q/ha)			Net income (₹/ha)			BC ratio			Yield (q/ha)			Net income (₹/ha)			BC ratio		
	2020	2021	Mean	2020	2021	Mean	2020	2021	Mean	2020	2021	Mean	2020	2021	Mean	2020	2021	Mean
T ₁	-	-	-	-	-	-	388.4	381.8	385.1	1177800	1193100	11,85,450	2.771	3.810	3.290			
T ₂	17.91	19.24	18.57	80,595	86,580	83,587	1.620	1.580	1.600	-	-	-	-	-	-			
T ₃	15.22	14.51	14.86	68,490	65,295	66,892	1.730	1.770	1.750	378.9	376.1	377.5	11,80,050	11,67,450	11,73,750	2.781	3.750	3.260
T ₄	14.54	14.88	14.71	65,430	66,960	66,195	1.760	1.750	1.760	376.8	385.0	379.9	11,25,600	12,16,500	11,71,050	2.650	3.861	3.260
T ₅	17.25	18.5	17.87	77,625	83,250	80,437	1.640	1.600	1.620	381.5	380.9	381.7	11,78,250	11,84,550	11,81,400	2.710	3.721	3.220
T ₆	17.53	16.33	16.93	78,885	73,485	76,185	1.630	1.680	1.660	380.4	381.2	380.8	11,86,800	11,72,400	11,79,600	2.730	3.701	3.210
CD (<i>p</i> =0.05%)	0.834			3,919			0.183			20.99			59,720			0.189		
SEd	0.374			1,759			0.082			9.423			26,802			0.084		

in soybean–maize relay cropping systems, respectively.

System productivity, land use efficiency, and profitability:

As a result of relay cropping, each crop had a shorter duration compared to sole crop. The sole cropping systems with banana and cotton required approximately 512 days to complete harvesting. The relay cropping system reduced this period to 415–422 days, resulting in a savings of 90–97 days. This reduction allowed for larger overall crop yields from the same area within the reduced period due to the increased number of crops grown in that area. The relay cropping system significantly influenced the productivity of both crops grown on the same land. During the relay cropping phase, system productivity, land use efficiency, and profitability improved (Table 2). Cotton grown as a relay crop achieved system productivity of 398.5 q/ha and 397.7 q/ha with six picking in T_5 and T_6 , respectively. Comparable results were obtained by Sandhu *et al.* (2020) in the strawberry–eggplant relay cropping system, who reported that the relay cropping system had no side effect on crop yield. Additionally, it enhances the total profit per hectare compared to planting two crops in the same field. Deshmukh *et al.* (2023) also found the same trend in the legume–castor relay cropping system. Integrating various crops in intricate spatial and temporal configurations can enhance resource utilisation efficiency and minimise detrimental environmental effects on agricultural lands (Rymbai *et al.* 2021, Chiesa *et al.* 2022). Likewise, Hoerning *et al.* (2020) found that the corn–soybean relay cropping system did not affect the yield of crops and reduced the weed biomass up to 100%.

Based on the performance of the relay cropping system, land use efficiency and production efficiency were evaluated (Table 2). Relay cropping systems were more efficient in land use and production compared to sole cotton crops. The T_5 and T_6 had land use efficiency of 126.9%. In contrast, cotton as a sole crop had a significantly lower land use efficiency of 40.27%. Similar was the case in the production efficiency.

Relay cropping significantly increased farmers' profits due to reduced input costs and higher crop yields (Table 2). According to the results, T_5 generated more profit at ₹3,457/ha/day compared to T_6 , which generated ₹3,440/ha/day. In contrast, the sole cotton crop yielded significantly lower profitability at ₹229/ha/day. Tripathi *et al.* (2021) observed a similar trend in the wheat–cucumber relay cropping system. Higher system productivity in relay cropping may result from the more efficient use of environmental resources compared to pure cropping, leading to higher yields. Additionally, the simultaneous growth of the two crops with minimal competition contributes to greater yield stability across multiple seasons and better utilisation of land resources due to differences in crop height, canopies, adaptation, and growth habits (Khongdee *et al.* 2021, Purnomo 2025). However, it is estimated that the productivity of crops in relay systems is still below their potential. A similar observation was made by Parajulee and Panta (2021) and Singh (2023).

Soil fertility status: An analysis of post-harvest soil

Table 2 Effect of banana–cotton relay cropping system on yield, net income, BCR, LUE, PE, and profitability

Treatment	Yield (q/ha)			Net income (₹/ha)			BCR			LUE (%)			PE (%)			Profitability (₹/ha/day)		
	2020	2021	Mean	2020	2021	Mean	2020	2021	Mean	2020	2021	Mean	2020	2021	Mean	2020	2021	Mean
T_1	388.4	381.8	385.1	11,77,800	11,93,100	1,17,7800	2.77	3.81	3.29	100	100	100	-	-	-	3,226	3,268	3,247
T_2	17.91	19.24	18.57	80,595	86,580	83,587	1.62	1.58	1.60	40.27	40.27	40.27	-	-	-	220.8	2,37.2	229
T_3	394.1	390.6	392.3	12,48,540	12,32,745	1,24,0643	4.51	5.51	5.01	113.6	138.3	126.0	78.04	94.12	86.08	3,420	3,377	3,399
T_4	391.3	401.8	396.6	11,91,030	12,83,460	1,23,7245	4.41	5.61	5.01	113.6	138.3	126.0	77.49	96.84	87.17	3,263	3,516	3,389
T_5	398.7	398.4	398.5	12,55,875	12,67,800	1,26,1838	4.35	5.32	4.84	115.6	138.3	126.9	78.96	94.41	86.68	3,440	3,473	3,457
T_6	397.9	397.5	397.7	12,65,685	12,45,885	1,25,5785	4.36	5.38	4.87	115.6	138.3	126.9	78.80	94.20	86.50	3,467	3,413	3,440
CD ($p=0.05\%$)			21.66			63,000			0.361			7.713			5.592			151.9
SEd			9.724			28274			0.162			3.462			2.509			68.17

BCR, Benefit cost ratio; LUE, Land use efficiency; PE, Production efficiency. Treatment details are given under Materials and Methods.

was carried out to determine how the relay cropping affects the available nutrient status of the soil (Fig. 2). The T_5 treatment resulted in significantly higher levels of available N, P, and K, at 367.3 kg/ha, 20.96 kg/ha, and 429.5 kg/ha, respectively. This was followed by the T_6 which recorded 362.6 kg/ha, 20.57 kg/ha, and 428.3 kg/ha N, P, and K levels, respectively. Similarly, the treatment where cotton was planted after banana as a sole crop also recorded higher soil nutrient availability. Conversely, soils without fertiliser application showed reduced nutrient availability. Cotton without fertiliser application appears to deplete soil nutrients more rapidly, potentially resulting in reduced soil fertility. Most cotton crops rely on residual nutrients from banana, and as a result, even with substantial manure application, the soil quality remains poor. Since both crops have deep roots, they exhaust available nutrients from the soil. Hence, the relay cropping system will not have an impact on soil fertility due to longer undisturbed soil cover and greater diversity (Leonel *et al.* 2024, Thompson *et al.* 2024). Singh *et al.* (2017) observed a similar trend in rice–lathyrus relay cropping system, Singh (2023) in the mustard–berseem and Yiling *et al.* (2023) in maize–soybean relay cropping system.

The study indicated that banana–cotton relay cropping enhances both productivity and income in farming systems. Regardless of land type, the cropping system plays a crucial role in achieving high yields and enhanced productivity. This technique not only maximises system productivity and reduces land preparation costs for the second crop but also significantly increases land use efficiency. However, the yields of both banana and cotton were unaffected by the relay cropping system in wetland ecosystems. Relay cropping with cotton in two rows, whether with or without fertiliser, is a promising alternative to double cropping in wetland conditions and delta regions. Future research should be focused on field level trials to further explore the significance of relay crops in banana cultivation, which play a critical role in improving the production, productivity, and income of farming communities. Detailed studies should

also be conducted to identify the most suitable banana and cotton varieties for relay cropping systems to examine the suitability of various crops in a relay system with banana under different farming conditions, and to evaluate the impact of different fertiliser doses. The residual effects of these practices on subsequent crops also need to be carefully studied for a comprehensive recommendation.

ACKNOWLEDGEMENT

The authors are greatly thankful to the Director, ICAR-ATARI, Hyderabad, India for providing the necessary financial support for this study.

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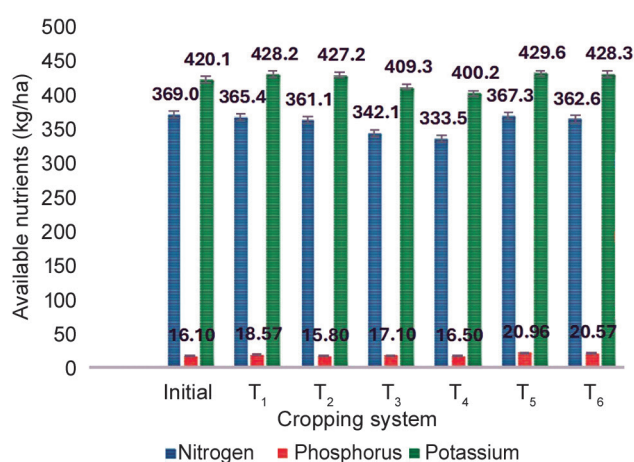


Fig. 2 Effect of banana–cotton relay cropping system on post-harvest soil nutrient status.

Treatment details are given under Materials and Methods.

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