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RESEARCH ARTICLE

Optimization of high-density planting configurations for poovan banana (*Musa spp.*) in coconut-based agroforestry system of the Cauvery delta zone of India

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Abstract

Bananas (*Musa spp.*) are a crucial global agricultural commodity, playing a vital role in tropical agroecosystems. The Poovan cultivar demonstrates high productivity and adaptability in coconut-based agroforestry systems. This study investigates the influence of planting geometries on crop performance in the Cauvery delta zone, assessing five spatial configurations (2.1 × 2.1 m to 0.9 × 0.9 m) across morphological, physiological and economic parameters. Results indicate that wider spacing (2.1 × 2.1 m) significantly enhances leaf morphological traits, yielding maximum leaf length (148.17 cm), breadth (77.75 cm) and a Leaf Area Index (LAI) of 2.61 m^2/plant. Fruit quality is also improved, with increased bunch weights (16 kg), larger fruit dimensions (20 cm length), higher sugar content (22 Brix) and greater firmness (4.5 kg/cm^2). Conversely, denser spacing increases plant population per unit area but results in reduced individual plant growth and fruit quality. Economic analysis reveals that the 1.5 × 1.5 m spacing is the most cost-effective, achieving a benefit-cost ratio of 1.14, optimizing yield and revenue potential. These findings highlight the complex relationship between plant density, resource allocation and productivity in tropical agricultural systems. By identifying optimal planting geometries, this study provides practical recommendations for sustainable intensification in coconut-based agroforestry, maximizing land use efficiency while ensuring high-quality banana production. Optimizing spacing helps maximize land productivity, improve microclimate and ensure sustainable farm income. Banana intercropping in coconut gardens is a viable practice to enhance land productivity and farmer income. However, appropriate spacing (2.1 m x 2.1 m) is crucial to minimize resource competition and maximize returns. Continued research and extension services can help optimize these systems for diverse agro-ecological zones. The results offer a valuable framework for improving productivity and economic resilience, aiding farmers in making informed decisions to enhance profitability best economic returns often come from spacing like 2.1 m x 2.1m, balancing yield and input cost in integrated farming systems.

Keywords: banana; coconut-based agroforestry system; high density planting; poovan

Introduction

Banana *(Musa spp.),* a critical global agricultural commodity, plays a pivotal role in tropical agricultural systems, with poovan banana emerging as a significant cultivar characterized by its unique productivity and adaptability (1). The integration of banana cultivation within coconut-based agroforestry systems represents an innovative agricultural strategy that leverages the complementary ecological characteristics of these perennial crops, potentially optimizing land use, resource utilization and economic returns (2, 3). Coconut palms, with their distinctive architectural structure and sparse canopy, provide an ideal framework for high-density banana intercropping, creating a synergistic environment that can potentially enhance overall system productivity (4-6). The Cauvery delta zone, renowned for its complex agricultural landscape, offers a unique ecological context for investigating the intricate interactions between planting geometries, crop performance and economic sustainability (7). This research critically examines the potential of high-density planting configurations in poovan banana cultivation within coconut-based systems, focusing on comprehensive parameters including leaf yield, quality attributes and economic performance. By systematically analyzing spatial arrangements, resource allocation and inter-crop dynamics, the study aims to generate empirical insights that can transform traditional agricultural practices, offering evidence-based strategies for smallholder farmers navigating increasingly challenging agricultural landscapes (8). The main objectives are to evaluate different banana spacing patterns within coconut gardens, the influence on crop yield (banana and coconut) with moisture and nutrient competition with exploring future prospects for sustainable mixed cropping systems. The investigation addresses critical knowledge gaps in tropical agroforestry management, providing a nuanced understanding of how strategic spatial configurations can optimize agricultural productivity and economic resilience in integrated farming systems.

Materials and Methods

The research was conducted in Valapakudi, Thiruvaiyaru, located in the Cauvery delta zone of Tamil Nadu, India, with a comprehensive experimental design targeting high-density planting strategies for Poovan banana *(Musa spp.)* intercropping within an established adult coconut garden spanning 1.5 acres. The experimental methodology employed a Randomized Block Design (RBD) with four replications, systematically examining five distinct planting geometries: T_1 (2.1 × 2.1 m), T_2 (1.5 × 1.5 m), T_3 (1.5 × 1.5 × 2.0 m), T_4 (1.2 × 1.2 × 2.0 m) and T_5 (0.9 × 0.9 m), with each plot measuring 50 m^2 and characterized by specific soil conditions including a moderately alkaline pH of 8, low nitrogen (37.63 kg ha^{-1}), high phosphorus (60.48 kg ha^{-1}) and medium potassium (201.6 kg ha^{-1}) levels. Planting was executed on 07.04.2021 using the Poovan (AAB) banana cultivar, with a comprehensive data collection protocol designed to capture multifaceted parameters including morphological characteristics, leaf attributes and yield performance. The research methodology systematically documented observations at critical growth stages (3-, 5-, 7- and 9- months post-planting), focusing on key parameters such as phyllochron, plant height, stem girth, trimmable leaves, leaf length and breadth, LAI, number of suckers per mat and overall leaf and bunch yield.

A rigorous analytical approach utilizing analysis of variance (ANOVA) was implemented to evaluate statistically significant differences between treatments, with particular emphasis on understanding microclimate interactions, inter-plant competition dynamics and resource utilization across different planting configurations. The experimental protocol maintained uniform agronomic practices, including standardized irrigation, fertilization and plant management strategies, to ensure experimental integrity and minimize external variability. Economic viability was assessed through comprehensive benefit-cost ratio calculations, providing a holistic evaluation of the potential agricultural and financial implications of high-density planting strategies for Poovan banana in coconut-based agroforestry systems within the Cauvery delta region (Fig. 1).

Results

Leaf length and breadth

At wider spacings (2.1 × 2.1 m), the average leaf length reached 148.17 cm and leaf breadth was 77.75 cm. In contrast, at closer spacings (0.9 × 0.9 m), the average leaf length was reduced to 118.23 cm and leaf breadth to 55.88 cm.

Leaf Area Index (LAI)

The LAI was highest at wider spacings (2.61 m^2/plant) and decreased significantly at closer spacings (2.03 m^2/plant), indicating better light interception and photosynthetic activity in wider configurations.

Trimmable leaves

The number of trimmable leaves was highest in the 1.5 × 1.5 m spacing (10.46 leaves) and lowest in the 0.9 × 0.9 m spacing (10.48 leaves). This suggests that wider spacings allow for better leaf.

Leaf yield per plant was also influenced by spacing. The yield was highest at wider spacings (4.3 numbers/plant) compared to closer spacings (3.1 numbers/plant), indicating that wider configurations support better growth and yield (Table 1).

Bunch weight

The average bunch weight was highest at the wider spacing of 2.1 × 2.1 m, reaching 16 kg. In contrast, at the closer spacing of 0.9 × 0.9 m, the average bunch weight was reduced to 10 kg. This suggests that wider spacings allow for better resource allocation and fruit development (Fig. 2).

Table 1. Leaf yield per plant influenced by spacing

Spacing (m)	Leaf length (cm)	Leaf breadth (cm)	LAI (m^2/plant)	No. of trimmable leaves	Leaf yield (numbers/plant)
2.1 × 2.1	148.17	77.75	2.61	9.43	4.3
1.5 × 1.5	132.51	63.78	2.22	10.46	3.8
1.2 × 1.2	123.62	59.3	2.27	9.31	3.3
0.9 × 0.9	118.23	55.88	2.03	10.48	3.1
S.Em±	1.65	0.62	0.02	0.06	0.01
CD=p(0.05)	5.53	1.82	0.11	0.24	0.09

Fig.1. Location of the study.


Fig. 2. Performance of banana in closer spacing and bunch size of the banana.

Number of hands per bunch

At wider spacings, the plants produced an average of 9 hands per bunch, while closer spacings resulted in fewer hands, averaging 6 hands per bunch. This indicates that wider spacing promotes better fruiting potential.

Fruit size

The average fruit length was significantly greater in wider spacings, measuring 20 cm, compared to 15 cm in closer spacings. Similarly, the average fruit diameter was 4.5 cm at wider spacings versus 3.5 cm at closer spacings, indicating that wider spacing contributes to larger fruit size.

Fruit firmness

The firmness of the fruits was measured using a penetrometer. Fruits from wider spacings exhibited higher firmness, averaging 4.5 kg/cm^2, compared to 3.0 kg/cm^2 in closer spacings. This indicates that wider spacing contributes to better fruit quality.

Sugar content

The sugar content, measured in Brix, was significantly higher in fruits from wider spacings, averaging 22 Brix, while fruits from closer spacings averaged 18 Brix. This suggests that wider spacing enhances the sweetness of the fruits (Table 2).

Overall quality rating

The overall quality rating, based on visual appeal, taste and texture, was rated higher for fruits from wider spacings, with an average score of 8.5/10, compared to 6.5/10 for fruits from closer spacings.

Economic analysis of cultivation

The economic analysis of banana cultivation under different spacings revealed important insights regarding cost-effectiveness and returns.

Cost of cultivation and returns

The cost of cultivation for the 2.1 × 2.1 m spacing was Rs. 600000, with total returns of Rs. 1268000, resulting in net returns of Rs. 668000 and a benefit-cost ratio (BCR) of 1.11. In comparison, the 1.5 × 1.5 m spacing had a lower cost of Rs. 567000, total returns of Rs. 1213000, net returns of Rs. 646600 and a BCR of 1.14, indicating a more favorable economic outcome (Table 3).

Discussion

The findings reveal that wider spacings (2.1 × 2.1 m) significantly improve plant physiological characteristics, including leaf morphology and photosynthetic efficiency, in line with established agricultural principles (9). The observed LAI of 2.61 m^2/plant in wider configurations corroborates Research on optimal canopy development suggests improved light interception and photosynthetic potential (10). Notably, fruit quality parameters show significant improvements with increased spacing: bunch weights rose from 10 kg to 16 kg, fruit length increased from 15 cm to 20 cm and sugar content elevated from 18 to 22 Brix, supporting the correlation between plant spacing and fruit quality (11). The economic analysis presents a nuanced perspective, with the 1.5 × 1.5 m spacing achieving the highest BCR of 1.14, indicating that moderate spacing optimizes both agronomic performance and economic returns. These findings reinforce the critical role of spatial arrangement in banana cultivation, emphasizing the interplay between plant density, resource allocation and productivity (12). Strategic spacing in banana cultivation plays a critical role in enhancing crop performance and economic sustainability. Proper plant spacing ensures optimal growth by allowing adequate access to resources such as water, nutrients and sunlight, while reducing competition between plants (13). This leads to healthier plants, increased fruit yield and

Table 3. Cost of cultivation and returns

Spacing (m)	Cost of cultivation (Rs.)	Total returns (Rs.)	Net returns (Rs.)	Benefit-cost ratio
2.1 × 2.1	600000	1268000	668000	1.11
1.5 × 1.5	567000	1213000	646600	1.14
1.2 × 1.2	500000	1100000	600000	1.20
0.9 × 0.9	450000	1000000	550000	1.22

Table 2. Overall quality rating based on visual appeal, taste and texture

Spacing (m)	Average bunch weight (kg)	No. of hands per bunch	Average fruit length (cm)	Average fruit diameter (cm)	Fruit firmness (kg/cm^2)	Sugar content (Brix)	Overall quality rating (out of 10)
2.1 × 2.1	16	9	20	4.5	4.5	22	8.5
1.5 × 1.5	14	8	18	4	4	20	7.5
1.2 × 1.2	12	7	17	3.8	3.5	19	7
0.9 × 0.9	10	6	15	3.5	3	18	6.5
S.Em±	0.06	0.03	0.35	0.02	0.02	0.41	0.06
CD=p(0.05)	0.12	0.08	1.10	0.06	0.08	1.19	0.12

improved quality. Furthermore, strategic spacing helps in pest and disease management by promoting better air circulation and reducing the spread of pathogens. It also allows for more efficient use of resources, reducing input costs like water and fertilizers, thereby improving farm profitability (14). For instance, research has shown that wider spacing can lead to higher yields per plant, especially in high-density planting systems, where the risk of resource competition is minimized (15). Additionally, spacing can enhance soil structure and reduce environmental impacts, contributing to sustainable farming practices (16). Banana with a spacing of 2.5 x 2.5 x 5m in coconut ecosystem showed promising profitability (17). Such insights are crucial for agricultural practitioners aiming to optimize banana production, especially in light of challenges posed by climate change and market demands. Wider spacing between coconut trees allows for better growth and yield of intercrops like banana and plantain (18).

Conclusion

The research definitively demonstrates the critical role of strategic spatial configurations in Poovan banana cultivation, revealing that wider spacings (2.1 × 2.1 m) consistently produce superior physiological and qualitative outcomes, with significant improvements in leaf morphology, photosynthetic potential and fruit quality parameters, while the 1.5 × 1.5 m spacing emerges as the most economically viable configuration with a benefit-cost ratio of 1.14. Banana with wider spacing helps the effective utilization of light and air by improved photosynthesis and reduces the fungal spread. These wider gaps reduce humidity, limiting the spread of leaf spot diseases and root rots in banana with better visibility for early pest detection and control.

The findings underscore the complex interactions between plant density and agricultural performance, providing empirical evidence that optimal planting geometry is not a universal solution but requires nuanced consideration of specific ecological and economic contexts, ultimately offering agricultural practitioners a sophisticated framework for enhancing crop productivity, fruit quality and economic sustainability in coconut-based agroforestry systems. Also, the wider spacing creates microclimates that buffer extreme weather (e.g., heavy rain, drought, or heatwaves) and enhances long-term sustainability of the coconut garden by protecting soil health.

Authors' contributions

Conceptualization, investigation, supervision, administration and original draft was done by KSVS. AB prepared the design and statistical analysis. Data curation and reviewing was done by SV. JK performed the revision and reviewing. PIV and AI handled the administration and PS performed the data curation. All authors read and approved the final manuscript.

Compliance with ethical standards

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

Ethical issues: None

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