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Optimization of High-Density Planting Configurations for Poovan Banana (*Musa spp*.) in Coconut-Based Agroforestry Systems of the Cauvery Delta Zone

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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

Bananas (*Musa spp*.) are a vital global agricultural commodity and an essential crop in tropical agricultural systems. The Poovan cultivar, known for its high productivity and adaptability, is particularly effective in intercropping within coconut-based agroforestry systems. This study

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investigates the impact of planting geometries on crop performance in the Cauvery Delta Zone by evaluating five spatial configurations, ranging from 2.1×2.1m to 0.9×0.9m, with a focus on morphological, physiological, and economic parameters. The results indicate that wider spacing configurations, especially 2.1×2.1m, significantly improve leaf morphological traits, including maximum leaf length (148.17 cm), breadth (77.75 cm), and leaf area index ($2.61m^2$/plant). Additionally, these configurations enhance key fruit quality characteristics, such as increased bunch weight (16kg), improved fruit dimensions (20cm length), higher sugar content (22°Brix), and greater fruit firmness ($4.5kg/cm^2$). The economic analysis suggests that a 1.5×1.5m spacing provides the most favorable cost-benefit ratio (1.14). This study offers valuable insights into the complex relationships between planting density, resource allocation, and productivity in tropical farming systems, providing evidence-based recommendations for optimizing both agricultural performance and economic viability in integrated farming systems.

Keywords: Banana; Poovan; high density planting; coconut eco system.

1. 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 (Swaminathan et al., 2022). 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 (Nair et al., 2021; (Coffi et al., 2023). 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 (Raman et al., 2023; Ibrahim & Yusuf, 2021; Kantharaju et al., 2024). 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 (Kumar & Murthy, 2022). 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 (Selvam et al., 2024). 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.

2. 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(2.1×2.1m), T_2 (1.5×1.5m), T_3 (1.5×1.5 ×2.0m), T_4 (1.2×1.2 ×2.0 m), and T_5 (0.9×0.9m), with each plot measuring 50 m² and characterized by specific soil conditions including a moderately alkaline pH of 8.0, 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, leaf area index, 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.

3. RESULTS

3.1 Leaf Length and Breadth

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

3.2 Leaf Area Index (LAI)

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

3.3 Trimmable Leaves

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

3.4 Leaf Yield

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

3.5 Bunch Weight

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

3.6 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.

3.7 Fruit Size

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

3.8 Fruit Firmness

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

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

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/cm²)	Sugar Content (^{0}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

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	6,00,000	12,68,000	6,68,000	1.11
1.5 × 1.5	5,67,000	12,13,000	6,46,600	1.14
1.2 × 1.2	5,00,000	11,00,000	6,00,000	1.20
0.9 × 0.9	4,50,000	10,00,000	5,50,000	1.22

Fig. 1. Performance of banana in closer spacing and bunch size of the banana

3.9 Sugar Content

The sugar content, measured in Degree Brix, was significantly higher in fruits from wider spacings, averaging 22^{0}Brix, while fruits from closer spacings averaged 18^{0}Brix. This suggests that wider spacing enhances the sweetness of the fruits.

3.10 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.

3.11 Economic Analysis of Cultivation

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

3.12 Cost of Cultivation and Returns

The cost of cultivation for the 2.1×2.1m spacing was Rs. 6,00,000, with total returns of Rs. 12,68,000, resulting in net returns of Rs. 6,68,000 and a benefit-cost ratio (BCR) of 1.11. In comparison, the 1.5×1.5m spacing had a lower cost of Rs. 5,67,000, total returns of Rs. 12,13,000, net returns of Rs. 6,46,600, and a BCR of 1.14, indicating a more favorable economic outcome.

4. DISCUSSION

The findings align with Soto-Ballestero's (2002) agricultural principles, revealing that wider spacings (2.1×2.1m) substantially enhance plant physiological characteristics, including leaf morphology and photosynthetic efficiency. The observed leaf area index (LAI) of 2.61 m²/plant in wider configurations corroborates Turner and Lahav's (1983) research on optimal canopy development, suggesting improved light interception and photosynthetic potential. Notably, the fruit quality parameters demonstrate remarkable improvements with increased spacing: bunch weights increased from 10kg to 16kg, fruit length expanded from 15cm to 20cm, and sugar content rose from 18to22^{0}Brix, supporting Chillet et al.'s (2006) findings on the correlation between plant spacing and fruit quality. The economic analysis reveals a nuanced perspective, with the 1.5×1.5m spacing presenting the most favorable benefit-cost ratio of 1.14, indicating that moderate spacing can optimize both agronomic performance and economic returns. These results substantiate previous studies by Kumar *et al.* (2017) on the critical role of spatial arrangement in banana cultivation, highlighting the complex interplay between plant density, resource allocation, and productivity. 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 (Mohan Kumar & Kunhamu, 2022). This leads to healthier plants, increased fruit yield, and 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 (Selva Rani et al., 2024). 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 (Dye, 2017). Additionally, spacing can enhance soil structure and reduce environmental impacts, contributing to sustainable farming practices (López et al., 2020). Such insights are crucial for agricultural practitioners aiming to optimize banana production, especially in light of challenges posed by climate change and market demands. Highest BCR was obtained with wider spacing, this finding was coincided with Tharani et al. (2024).

5. CONCLUSION

The research definitively demonstrates the critical role of strategic spatial configurations in Poovan banana cultivation, revealing that wider spacings (2.1×2.1m) consistently produce superior physiological and qualitative outcomes, with significant improvements in leaf morphology, photosynthetic potential, and fruit quality parameters, while the 1.5×1.5m spacing emerges as the most economically viable configuration with a benefit-cost ratio of 1.14. 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.

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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