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Impact of Spacing on Soil Microbial Populations, Pest and Disease Incidence in Cocoa Cultivation

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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

Cocoa (*Theobroma cacao*) is a globally important commercial crop prized for its delicious and versatile beans used in chocolate production. However, cocoa cultivation faces significant challenges, including pest and disease outbreaks that can devastate yields and farmer livelihoods. One potential approach to managing these challenges is optimizing agricultural practices, including planting density or crop spacing. This study aimed to investigate the impact of different planting densities on these factors to identify an optimal spacing strategy that promotes a healthy soil microbiome, reduces pest and disease problems, and ultimately enhances cocoa yields. The experiment was laid out in Randomized Block Design (RBD) with eight treatments and three replications. Results revealed that T7 (2.5m) exhibited the lowest incidence of pod rot (0.48), while

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T6 (2m) had the least mealy bug infestation (0.55). Notably, T6 showed the highest bacterial population (7.33 × 106 CFU g-1), whereas T4 (3 x 3 m) and T7 (2.5m) demonstrated higher fungal populations (3.33 × 104 CFU g-1). Furthermore, T3 (3m x 2.5m) displayed the highest actinomycetes population (4.33 × 103 CFU g-1). These findings underscore the importance of spacing configurations in influencing soil microbial populations and pest and disease incidence in cocoa cultivation.

Keywords: Cocoa; planting density; soil microbiome; pod rot; mealy bug.

1. INTRODUCTION

Cocoa, scientifically known as *Theobroma cacao* L., originates from the Amazon region of South America and holds significant importance as a plantation crop. Belonging to the Malvaceae family, cocoa is cultivated predominantly in the humid tropics between 20ºN and 20ºS latitude, with optimal growth occurring between 10º N and 10º S [1]. It thrives best at an elevation of around 300 meters above sea level, requiring annual precipitation between 1500-2000 mm and temperatures ranging from 15-39°C, with an optimum temperature of approximately 25°C. High humidity levels are essential throughout the year for its optimal growth. While there are over 20 species in the Theobroma genus, T. cacao is the only cultivable species, characterized by its diploid nature with 20 chromosomes in somatic cells (2n=20).

Although cocoa has a long history of cultivation in Central America, its introduction to Africa and Asia is more recent. Commercial cultivation began in India in the early 1970s, with South India being the primary focus. In South India, cocoa is typically intercropped with coconut plantations, except in Kerala where it is grown alongside forest trees and rubber [2-4]. Kerala contributes to the majority of cocoa cultivation in India, with about 76% of the area and 78% of the total production, while Karnataka and Tamil Nadu also contribute to production.

The global demand for cocoa beans has been steadily rising, with an estimated additional one million metric tonnes required by 2030 to meet demand [5]. However, the supply of cocoa beans from major producing countries has been inconsistent, particularly due to low output from Côte d'Ivoire, the largest cocoa-producing country. Cocoa cultivation primarily serves the production of chocolate, with various by-products utilized in industries such as cosmetics, confectioneries, perfumeries, and pharmaceuticals [6].

The high-density planting (HDP) method, developed in the 1980s by the Ministry of Agriculture, Land, and Marine Resources (MALMR), offers an alternative to conventional low-density planting (LDP) systems, to boost crop productivity and profitability [7]. HDP aims to maximize yield per unit area by increasing plant density, leading to higher overall yields despite lower individual plant yields [8,9] (Olufemi *et al*., 2020) [10] (Armstrong, 1976). The primary objective is to enhance productivity and sustainability by extracting the maximum useful biomass from limited land resources, particularly crucial given the diminishing size of land holdings [11,12].

In cocoa farming, HDP may involve planting double rows of cocoa plants between coconut rows, followed by early plant training and regular pruning to optimize canopy development and microclimate conditions [13]. Effective nutrient management is essential in HDP systems to prevent decreased yields associated with conventional fertilizer applications. The adoption of well-organized high-density cocoa within coconut plantations has demonstrated potential for profitability, as proposed for consideration by cocoa growers in Ghana [13].

2. MATERIALS AND METHODS

The research, titled " Impact of spacing on soil microbial population, pest and diseases incidence in cocoa cultivation " was conducted at the Department of Spices and Plantation Crops, Horticultural College and Research Institute, which is part of the Tamil Nadu Agricultural University situated in Coimbatore, Tamil Nadu. Over one year, cocoa trees planted using high-density methods at the Coconut Farm in Coimbatore were evaluated for productivity and quality during two specific seasons: July to December and January to June.

Table 1. Experimental details

Design	**:**	**RBD**
Treatments	:	Eight
Replications	:	Three
Age of the crop	:	4 years

Table 2. Treatment details

Treatment	Details
Double row of cocoa between two coconut rows	
T1	3m x 1.2m
T2	3m x 2m
T3	3m x 2.5m
T4	3m x 3m
Single row of cocoa between two coconut rows	
T5	1.5m
T6	2m
T7	2.5m
T8	3m

The study involved assessing the incidence of pests and diseases, specifically the number of cocoa pods affected by pod rot caused by Phytophthora palmivora, as well as the number of pods affected by mealy bugs, across different spacing treatments during both seasons. Additionally, microbial parameters were examined by analyzing soil samples to enumerate total bacteria, fungi, and actinomycetes using serial dilution and plating techniques. Enumeration of bacterial populations was conducted on soil extract agar medium, while enumeration of fungal populations was carried out on Rose Bengal Agar medium. References for the enumeration methods include James [14] for bacterial population enumeration and Parkinson et al. [15] for fungal population enumeration. The enumeration of actinomycetes population under varied spacing conditions was conducted using Kenknight's Agar medium. After a 7-day incubation period at 37°C, actinomycetes colonies were counted and expressed as colony-forming units per gram of dry soil, following the methodology outlined by Wellington and Toth [2].

Statistical analysis: The results were subjected to statistical analysis using AGRES SOFTWARE to compare the impact of spacing on soil microbial population, pest and disease incidence in cocoa cultivation

3. RESULTS AND DISCUSSION

The incidence of pod rot in cocoa pods exhibited notable variations across different spacing treatments during both seasons of the study. In the first season, the lowest number of pods affected by pod rot (0.13) was observed under T7 (2.5m), while the highest number (4.01) occurred under T1 (3m x 1.2m). Similarly, during the second season, significant differences were noted, with the minimum number of affected pods (0.83) recorded under T7 (2.5m), and the maximum number (8.16) observed under T1 (3m x 1.2m).

Among the eight spacing configurations studied, significant differences were observed in the number of pods affected by mealy bugs per tree during the first season. The lowest number (0.44) of affected pods per tree was recorded under T6 (2m), while the highest number was observed under T2 (3m x 2m) (4.22).

In the second season, significant variations were also noted in the number of pods affected by mealy bugs across different spacing treatments. The minimum number of affected pods (0.21) was observed under T8 (3m), whereas T2 (3m x 2m) showed the highest level of infestation (7.39).

Table 3. Effect of different spacing on number of pods affected by pod rot (Phytophthora palmivora) for per tree for different seasons in cocoa

Treatment	**Number of pods affected by pod rot (*Phytophthora palmivora)* per tree**		
	Season I	**Season II**	**Mean**
T1 – 3m x 1.2m	4.01	8.16	6.08
T2 – 3m x 2m	2.47	3.07	2.77
T3 – 3m x 2.5m	1.24	2.27	1.75
T4 - 3m x 3m	1.09	1.49	1.29
T5 - 1.5m	2.63	2.81	2.72
T6 – 2m	2.41	2.71	2.56
T7 - 2.5m	0.13	0.83	0.48
T8 – 3m	1.02	1.72	1.37
Mean	1.87	2.88	
SE(d)	0.049	0.041	
CD (0.05)	0.10**	0.08**	

*** - Highly significant*

Season I – July to December *Season II- January to June*

Table 4. Effect of different spacing on number of pods affected by mealy bug per tree for different seasons in cocoa

Treatment	Number of pods affected by Mealy bug per tree		
	Season I	**Season II**	**Mean**
T1 – 3m x 1.2m	0.94	1.92	5.52
T2 – 3m x 2m	4.22	7.39	5.77
T3 – 3m x 2.5m	1.66	0.76	1.43
T4 - 3m x 3m	4.16	6.82	1.21
T5 - 1.5m	0.55	2.19	1.37
T6 – 2m	0.44	0.67	0.55
T7 - 2.5m	1.44	3.46	2.45
T8 – 3m	0.97	0.21	0.59
Mean	1.79	2.92	
SE(d)	0.05	0.08	
CD (0.05)	0.12**	0.17**	

*** - Highly significant*

Season I – July to December *Season II- January to June*

The findings of the current study indicate that the lowest incidence of pod rot was observed in T7 (2.5m), possibly due to increased light penetration and decreased field humidity, conditions that are less conducive to pathogen survival. This aligns with the observations of Kamaldeo et al. [7], who reported reduced inoculum pressure of pathogens under low-density planting. However, it's noted that higher levels of management within high-density planting (HDP), including regular pruning and shade management, along with the cultivation of cocoa clones tolerant to black pod disease, can further reduce the incidence of pod rot even at closer spacing.

The bacterial population exhibited notable variations among the treatments studied, with the highest population (7.33 x 106 CFU g-1) observed in T6 (2m), while T4 (3m x 3m) and T8 (3m) showed the lowest values (2.33 x 106 CFU g-1). Similarly, significant differences were noted in the fungal population across different spacing treatments. The maximum fungal population (3.33 x 104 CFU g-1) was recorded under T4 (3m x 3m) and T7 (2.5m), while the lowest population (1.33 x 104 CFU g-1) was observed in T2 (3m x 2m) and T5 (1.5m). In terms of actinomycetes population, significant variations were observed among the spacing levels. The highest population (4.33 x 103 CFU g-1) was found in T3 (3m x 2.5m), while the lowest (2.33 x 103 CFU g-1) was registered in treatments T1 (3m x 1.2m) and T6 (2m).

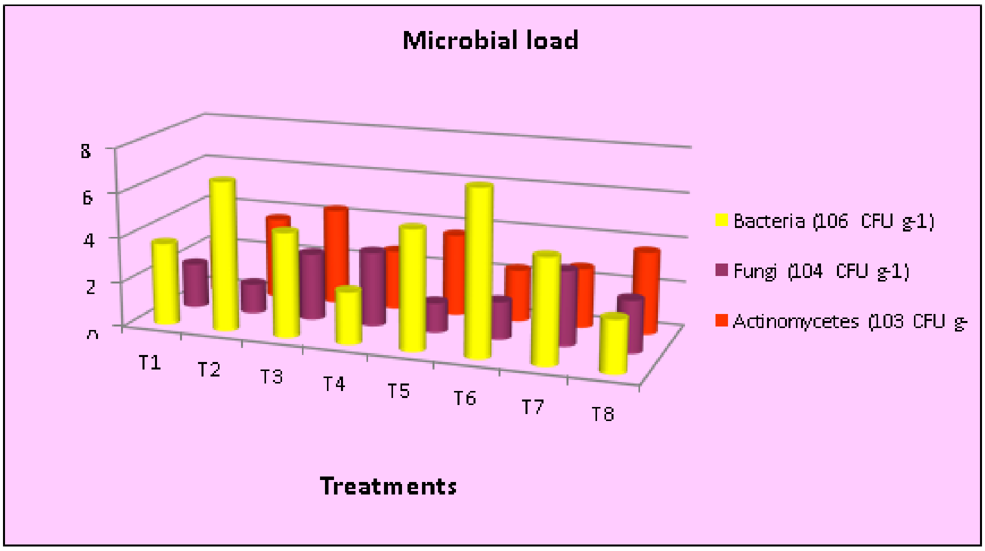

Fig. 1. Effect of different spacing on bacteria, fungi and bacterial population in soil

Table 5. Effect of different spacing on bacteria, fungi and bacterial population in soil

Treatment	Bacteria Population × 10^6 CFU g^{-1}	Fungi Population × 10^4 CFU g^{-1}	Actinomycetes Population × 10^3 CFU g^{-1}
T1 – 3m x 1.2m	3.67 (0.56)	2.00 (0.30)	2.33 (0.37)
T2 – 3m x 2m	6.67 (0.82)	1.33 (0.12)	3.67 (0.56)
T3 – 3m x 2.5m	4.67 (0.67)	3.00 (0.48)	4.33 (0.64)
T4 - 3m x 3m	2.33 (0.37)	3.33 (0.52)	2.67 (0.43)
T5 - 1.5m	5.33 (0.73)	1.33 (0.12)	3.67 (0.56)
T6 – 2m	7.33 (0.87)	1.67 (0.22)	2.33 (0.37)
T7 - 2.5m	4.67 (0.67)	3.33 (0.52)	2.67 (0.43)
T8 – 3m	2.33 (0.37)	2.33 (0.37)	3.67 (0.56)
Mean	4.625 (0.67)	2.29 (0.36)	3.16 (0.38)
SE(d)	0.119	0.011	0.011
CD (0.05)	0.257**	0.025**	0.025**

*** - Highly significant*

Season I – July to December *Season II- January to June*

The impact of various cocoa spacing configurations on soil microbial populations, including bacteria, fungi, and actinomycetes, exhibited significant variations. The highest bacterial population was observed in T6 (2m), while T4 (3m x 3m) and T7 (2.5m) showed the highest fungal population. Additionally, T3 (3m x 2.5m) demonstrated the highest population of actinomycetes. The association of cocoa with coconut has been reported to enhance microbial numbers within the coconut rhizosphere [16]. This phenomenon can be attributed to the increased light interception within widely spaced cropping systems, creating conditions conducive to microbial proliferation [17].

4. CONCLUSION

This study investigated the impact of planting density on soil microbial communities and pest/disease incidence in cocoa cultivation. A significant correlation was observed between spacing configurations and these factors. Notably, closer spacing arrangements (2m and 2.5m) exhibited a lower prevalence of pod rot and mealybug infestation compared to wider spacings. Furthermore, the composition of the soil microbiome varied with planting density. Plots spaced 2 meters apart harbored the highest bacterial population, while those spaced 3 x 3 meters and 2.5 meters demonstrated higher fungal populations. Interestingly, the highest population of actinomycetes was found in plots with a 3 meters x 2.5 meters spacing. These findings suggest that optimizing planting density has the potential to promote beneficial soil microbes while concurrently mitigating pest and disease pressure in cocoa production. Future research should delve deeper into the mechanisms underlying this relationship and evaluate the long-term effects of these strategies on cocoa yield and overall farm productivity. Ultimately, a comprehensive approach that considers soil health, pest management, and crop yield can guide cocoa farmers toward sustainable and productive cultivation 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 manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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