Archives of Current Research International

Volume 24, Issue 9, Page 237-244, 2024; Article no.ACRI.117889
ISSN: 2454-7077

Impact of High-density Planting Spacing on Physiological Traits of Cocoa Grown under Coconut Trees

Jegadeeswari. V [a], K. Padmadevi [b*], Vijayalatha. K. R [a], M. Mohanalaksmi [c], J. Kalaivani [a] and G. Sidhdharth [a]

[a] *Horticultural College and Research Institute for Women, Tiruchirappalli, India.*
[b] *Horticultural College and Research Institute, Coimbatore, India.*
[c] *Agricultural College and Research Institute, Karur, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/acri/2024/v24i9889

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/117889

Original Research Article

Received: 30/03/2024
Accepted: 01/06/2024
Published: 19/09/2024

ABSTRACT

High-density planting (HDP) maximizes land productivity. Optimizing cocoa spacing under coconut trees enhances physiological traits and yield potential. Despite cocoa's integration into coconut agroforestry, spacing's impact on cocoa physiology is unclear. Studying this influence provides insights for better planting strategies, improved crop performance, and sustainable cocoa production in agroforestry settings. The experiment was conducted at the Coconut Farm of the Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore. Employing a Randomized Block Design (RBD) with eight treatments replicated three times, the study aimed to explore how different spacing levels influence physiological traits in cocoa cultivation. The treatments involved in the experiment included a double row of cocoa planted

**Corresponding author: Email: padhu.hort@gmail.com;*

Cite as: *V, Jegadeeswari., K. Padmadevi, Vijayalatha. K. R, M. Mohanalaksmi, J. Kalaivani, and G. Sidhdharth. 2024. "Impact of High-Density Planting Spacing on Physiological Traits of Cocoa Grown under Coconut Trees". Archives of Current Research International 24 (9):237-44. https://doi.org/10.9734/acri/2024/v24i9889.*

between two rows of coconut trees, with spacing configurations as follows: T1 (3m x 1.2m), T2 (3m x 2m), T3 (3m x 2.5m), and T4 (3m x 3m). Additionally, a single row of cocoa between two coconut rows was examined, with spacings represented by T5 (1.5m), T6 (2m), T7 (2.5m), and T8 (3m). Results indicated distinct patterns among spacing treatments, with significant differences observed in various physiological characteristics. Notably, T1 (3m x 1.2m) demonstrated the highest leaf area (462.71cm^2) and leaf area index (4.85), while T8 (3m) exhibited the highest light interception (74.12%). Additionally, T3 (3m x 2.5m) showcased the highest chlorophyll index (40.52) in cocoa leaves. These findings underscore the importance of spacing configurations in influencing key physiological parameters in cocoa cultivation, providing valuable insights for optimizing planting practices.

Keywords: Cocoa; spacing; leaf area; chlorophyll.

1. INTRODUCTION

Cocoa, originating from the Amazon region, is a vital plantation crop within the Theobroma genus of the Malvaceae family. It thrives in humid tropical climates between 20º N and 20º S, preferably at around 300 meters above sea level, with annual precipitation of 1500 to 2000mm and temperatures ranging from 15 to 39°C [1]. T. cacao, the sole cultivable species within the genus, has been cultivated in India since the early 1970s, primarily in South India, notably Kerala. With global demand steadily rising, projections suggest a need for an additional one million metric tonnes of cocoa by 2030. Cocoa cultivation primarily serves the chocolate industry, with its by-products utilized across various sectors. The cocoa tree, relatively small at 8-12 meters, features simple, shiny, dark green leaves and small cauliflorous flowers ranging from yellowish-white to pale pink. The fruit is an indehiscent drupe or pod containing 20-60 seeds enveloped in sweet mucilage [2].

During the 1980s, the Ministry of Agriculture, Land, and Marine Resources (MALMR) introduced High Density Planting (HDP) technology as an alternative to traditional Low Density Planting (LDP) systems [3]. HDP aims to achieve earlier cropping, consistent high yields, and improved farm management practices, ultimately increasing productivity and profitability by maximizing yield per unit area of land [4,5,6]. Despite potentially lower yield per plant, HDP significantly boosts overall yield due to a larger plant population [7,8], aligning with the primary goal of enhancing productivity and sustainability within limited land resources [9]. In cocoa cultivation, High Density Planting (HDP) involves planting double rows of cocoa plants between two rows of coconut trees. The concept of arranging high-density cocoa within widely spaced coconut trees has been suggested as a profitable intercrop system for cocoa farmers, particularly in Ghana [10]. In cocoa cultivation, integrating cocoa trees within coconut agroforestry offers potential for sustainable land management and increased yields. However, a significant gap exists in understanding how different planting spacing configurations affect cocoa plant physiology under coconut trees.

This study aims to investigate how high-density planting spacing affects cocoa's physiological traits under coconut trees. We'll explore variations in spacing configurations and their influence on key parameters like leaf area, chlorophyll content, and light interception. Our findings aim to offer valuable insights into optimal spacing practices for cocoa cultivation within coconut agroforestry systems. Limited research has specifically explored the physiological responses of cocoa plants to different spacing configurations within coconut agroforestry settings, despite the importance of optimizing planting spacing for crop performance and yield potential. This study aims to enhance existing knowledge by investigating the relationship between planting spacing and cocoa physiology in coconut agroforestry. Determining the most effective spacing configurations provides actionable guidance for cocoa cultivators, extension services, and policymakers. This supports the sustainability of cocoa production and strengthens the resilience of agroforestry systems.

2. MATERIALS AND METHODS

2.1 Experimental Site

The study titled "Impact of Spacing on Physiological Characters in Cocoa" was conducted at the Department of Spices and Plantation Crops, Horticultural College and Research Institute, Tamil Nadu Agricultural

List 1. 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

University, situated in Coimbatore, Tamil Nadu. The research extended over a year and focused on cocoa trees grown using high-density techniques at the Coconut Farm in Coimbatore. The experimental site experienced humid tropical conditions with average annual temperatures ranging between 20°C to 35°C. Annual precipitation was approximately 1500mm to 2000mm. These environmental factors create an ideal climate for cocoa cultivation, providing the necessary warmth and moisture for optimal growth and development of cocoa trees.

The crop management practices for this study included the use of 4-year-old cocoa trees of the Forestro variety. Irrigation was managed through a drip irrigation system to ensure consistent moisture levels. Standard fertilization practices were followed, with adjustments made based on soil test results to meet the specific nutrient requirements of the plants. Regular pruning and training were conducted to maintain canopy structure and overall plant health, facilitating better growth and productivity

2.2 Experimental Design

- **Design:** Randomized Block Design (RBD)
- **Plot Size:** Each plot measured 3m x 3m.
- **Replications:** Three replications for each treatment.
- **Treatments:** Eight different spacing configurations were used, divided into double and single rows of cocoa between two rows of coconut trees.

Data collection and sampling methods included measuring the leaf area by assessing the length and breadth of a standard leaf in five plants per replication under different spacing conditions for both seasons. Sampling methods involved taking measurements for leaf area and Leaf Area Index (LAI) from five randomly selected plants per replication. For light penetration and chlorophyll content, measurements were taken from three randomly selected points within each plot. This approach ensured a representative sample and accurate assessment of the physiological traits under different spacing conditions. The leaf area was estimated using the formula: Leaf Area = Length × Breadth × (0.666 + 0.73), incorporating the cocoa leaf calibration factor suggested by Bismark [11]. The Leaf Area Index (LAI) was calculated according to the method outlined by Williams (1946) for each season and spacing condition, defined as the total leaf area of a plant divided by the ground area occupied by the plant. Light penetration was assessed using a Konica Minolta light meter across the different spacing setups for both seasons. Chlorophyll content was measured using a chlorophyll index (Konica Minolta) to gauge leaf chlorophyll levels under varying spacing conditions. This non-destructive method, proposed by Yadava [12], utilized SPAD values based on light intensities in specific wavelength bands associated with chlorophyll absorption.

2.3 Data Analysis

Statistical analysis was conducted using ANOVA to determine the significance of differences among treatments. Means were compared using the Least Significant Difference (LSD) test at a 5% significance level.

3. RESULTS AND DISCUSSION

In Season I (July to December), significant differences were observed in tree height among the eight different spacings studied for cocoa (Table 1). The maximum height (2.24m) was recorded in T1 (3m x 1.2m), while the minimum height (1.46m) was observed in T4 (3m x 3m), which was statistically comparable to T2 (3m x 2m) and T6 (2m) with heights of 1.55m and

1.54m, respectively. In Season II (January to June), tree height ranged from 2.42m to 1.66m across different spacings. Stem girth was significantly influenced by spacing in both seasons (Table 2), with the highest girth recorded in T6 (2m) during Season I (16.31cm) and Season II (17.33cm). The lowest girth was observed in T8 (3m) during Season I (9.06cm) and T4 (3m x 3m) during Season II (12.60cm). The number of fan branches per tree ranged from three to four across both seasons, with the highest number (4.87) observed in T5 (1.5m) and the lowest (3.35) in T4 (3m x 3m).

The leaf area of cocoa plants exhibited significant differences across various spacing configurations in both seasons (Table 3). In Season I, the maximum leaf area was observed in T1 (3m x 1.2m), while T8 (3m) recorded the minimum leaf area. Similarly, in Season II, T1 (3m x 1.2m) showed the highest leaf area, whereas T4 (3m x 3m) exhibited the lowest. Leaf area index also varied significantly among different spacings, with T1 (3m x 1.2m) consistently showing the highest values (Table 4).

Light penetration, expressed as the percentage of light interception, differed significantly across spacings in both seasons (Table 5). T8 (3m) had the highest light interception in Season I, while in Season II, it was statistically on par with T6 (2m) and T7 (2.5m). The lowest light interception was observed in T1 (3m x 1.2m) during both seasons. Total chlorophyll content showed significant differences (Table 6) only in Season II, with T5 (1.5m) exhibiting the highest value and T7 (2.5m) the lowest. These findings highlight the influence of spacing on leaf area, light penetration, and chlorophyll content in cocoa plants across different seasons.

Table 1. Effect of different spacing on tree height for different seasons in cocoa

Treatment	Tree height (m)		
	Season I	**Season II**	**Mean**
T1 – 3m x 1.2m	2.24	2.42	2.33
T2 – 3m x 2m	1.55	2.04	1.80
T3 – 3m x 2.5m	1.68	1.75	1.71
T4 - 3m x 3m	1.46	1.78	1.62
T5 - 1.5m	1.89	2.17	2.03
T6 – 2m	1.54	1.88	1.71
T7 - 2.5m	1.66	1.66	1.66
T8 – 3m	1.90	2.25	2.07
Mean	**1.74**	**1.99**	
SE(d)	**0.036**	**0.039**	
CD (0.05)	**0.078****	**0.084****	

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

Table 2. Effect of different spacing on stem girth and number of fan branches for different seasons in cocoa

Treatment	Stem girth (cm)			Number of fan branches
	Season I	**Season II**	**Mean**	
T1 – 3m x 1.2m	11.36	11.56	11.46	3.85
T2 – 3m x 2m	13.30	14.23	13.76	4.57
T3 – 3m x 2.5m	13.28	14.33	13.80	4.43
T4 - 3m x 3m	10.21	12.60	11.40	3.35
T5 - 1.5m	13.08	13.66	13.37	4.87
T6 – 2m	16.31	17.33	16.82	3.86
T7 - 2.5m	10.04	13.06	11.55	4.10
T8 – 3m	9.06	12.80	10.93	3.60
Mean	**12.07**	**13.69**		**4.078**
SE(d)	**0.13**	**0.24**		**0.0850**
CD (0.05)	**0.29****	**0.51****		**0.1824****

Table 3. Effect of different spacing on leaf area for different seasons in cocoa

Treatment	Leaf area (LA) (cm^2)		
	Season I	**Season II**	**Mean**
T1 – 3m x 1.2m	428.59	490.79	462.71
T2 – 3m x 2m	386.94	412.98	426.77
T3 – 3m x 2.5m	292.13	478.79	400.53
T4 - 3m x 3m	276.45	302.51	339.14
T5 - 1.5m	247.74	340.29	328.50
T6 – 2m	225.27	317.08	326.56
T7 - 2.5m	241.09	486.62	359.04
T8 – 3m	220.81	389.27	353.39
Mean	**289.88**	**402.29**	
SE(d)	**6.54**	**10.54**	
CD (0.05)	**14.03****	**22.62****	

*** - Highly significant*

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

Table 4. Effect of different spacing on leaf area index for different seasons in cocoa

Treatment	Leaf area index (LAI)		
	Season I	**Season II**	**Mean**
T1 – 3m x 1.2m	4.69	5.02	4.85
T2 – 3m x 2m	1.97	2.24	2.11
T3 – 3m x 2.5m	0.99	1.62	1.30
T4 - 3m x 3m	0.59	0.81	0.70
T5 - 1.5m	0.66	1.20	0.93
T6 – 2m	0.46	0.59	0.53
T7 - 2.5m	0.24	0.55	0.40
T8 – 3m	0.23	0.25	0.24
Mean	**1.22**	**1.53**	
SE(d)	**0.54**	**0.02**	
CD (0.05)	**1.17****	**0.06****	

Table 5. Effect of different spacing on light interception for different seasons in cocoa

Treatment	Light interception (percent)		
	Season I	**Season II**	**Mean**
T1 – 3m x 1.2m	73.30 (58.88)	79.15 (62.83)	76.22
T2 – 3m x 2m	73.75 (59.18)	80.17 (63.55)	76.96
T3 – 3m x 2.5m	86.30 (68.27)	86.88 (68.76)	86.59
T4 - 3m x 3m	90.89 (72.43)	86.44 (68.39)	88.66
T5 - 1.5m	90.77 (72.31)	87.10 (68.95)	88.93
T6 – 2m	92.30 (73.89)	91.26 (72.80)	91.78
T7 - 2.5m	88.48 (70.16)	89.39 (70.99)	88.93
T8 – 3m	92.32 (73.91)	92.72 (74.34)	92.52
Mean	**86.01 (68.03)**	**86.63 (68.56)**	
SE(d)	**1.05**	**1.58**	
CD (0.05)	**2.27****	**3.40****	

Baihaqi et al. [13] observed that cocoa clones grown at lower planting densities exhibited increased vigor and stem girth, attributed to enhanced exposure to light [14]. This finding suggests that reduced planting densities contribute to maximizing stem girth in cocoa plants. Koko [15] highlighted that intercropped cocoa trees are generally smaller than those grown in monoculture [16]. These findings illustrate the intricate relationship between planting density, morphological traits, and cocoa growth dynamics, providing valuable insights into optimal cultivation practices for enhancing productivity and quality.

Table 6. Effect of different spacing on total chlorophyll content for different seasons in cocoa

Treatment	Total chlorophyll content (SPAD value)		
	Season I	Season II	Mean
T1 – 3m x 1.2m	33.25	46.42	39.78
T2 – 3m x 2m	34.48	39.87	40.49
T3 – 3m x 2.5m	34.60	46.81	40.52
T4 - 3m x 3m	34.10	43.96	37.02
T5 - 1.5m	36.02	51.07	37.94
T6 – 2m	34.26	48.51	37.04
T7 - 2.5m	30.00	50.14	38.56
T8 – 3m	31.66	40.84	39.02
Mean	**33.54**	**42.09**	
SE(d)	**3.80**	**1.00**	
CD (0.05)	**8.15^{NS}**	**2.14****	

Physiological parameters such as leaf area, leaf area index, chlorophyll content, and light penetration play crucial roles in determining the optimal growth and yield of cocoa crops. In the present study, maximum leaf area was observed in treatment T1 (3m × 1.2m), indicating a dense canopy and consequently lower light interception. Canopy spread, influenced by leaf number and area, is pivotal for effectively harnessing light energy for photosynthesis [17,18]. As indicated by Ewel et al. [19], leaf area is inversely related to light transmission [20]. The results of the current investigation revealed that treatment T8 (3m) exhibited the least leaf area and highest light transmission, resulting in prolific flowering. Asomaning et al. [21] reported a decrease in yield when the received light falls below 1800 hours per year [22]. Similarly, Koko et al. [15] demonstrated a positive correlation between incident light and cocoa yields, emphasizing its significance in determining plant vigor [23]. Thus, incident light serves as a valuable indicator for optimizing the spatial arrangement of cocoa under coconut canopy. Treatment T5 (1.5m) exhibited higher chlorophyll content due to its greater light interception (72.31%) [24-26].

4. CONCLUSION

The examination of physiological characters under varied crop spacing conditions revealed notable findings. Specifically, T1 (3m x 1.2m) exhibited the highest leaf area of 462.71cm2 and leaf area index of 4.85, indicating a robust canopy structure conducive to efficient photosynthesis. Conversely, T8 (3m) demonstrated the highest light interception at 74.12 per cent, suggesting effective light utilization despite potentially sparse foliage. Additionally, T3 (3m x 2.5m) showcased the highest chlorophyll index at 40.52, indicative of optimal leaf health and photosynthetic activity. These results underscore the intricate relationship between crop spacing and physiological parameters, highlighting the importance of strategic spacing configurations in maximizing cocoa plant performance and yield.

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.

REFERENCES

1. Goradevaishali S. Identification of molecular marker for self-incompatibility in selected germplasm accessions of cocoa (*Theobroma cacao* L.) (Doctoral dissertation, College of Horticulture, Vellanikkara); 2015.
2. Afoakwa EO. Cocoa production and processing technology. CRC Press; 2014.
3. Kamaldeo M, Indalsingh T, Ramnath D, Cumberbatch A. High density planting of cacao: The trinidad and tobago experience. In: International Workshop on Cocoa Breeding for Improved Production Systems, Accra, Ghana. 2003; 171-182.

4. Ladaniya MS, Marathe RA, Das AK, Rao CN, Huchche AD, Shirgure PS, Murkute AA. High density planting studies in acid lime (*Citrus aurantifolia* Swingle). Scientia Horticulturae. 2020;261: 108935.
5. Anthony BM, Minas IS. Optimizing peach tree canopy architecture for efficient light use, increased productivity and improved fruit quality. Agronomy. 2021;11(10): 1961.
6. Cortes S, Perez A. Influence of high planting densities on yields and bean quality. In: Min. of Agric. Lands and Marine Resources, Trinidad. 1986;4(2):29-39.
7. Olufemi AK, Olatunde FA, Adewale AS, Mohammed I, Osasogie U, Efe AF, Adeyemi OF. Effect of high density planting on the vigour and yield of *Theobroma cacao* L. in the Southwest of Nigeria. World Journal of Advanced Research and Reviews. 2020;8(1):217-223.
8. Armstrong KB. A spacing trial with single and multiple stem cocoa. In: Proc. of the Seminar on Cocoa and Coconuts, Taiwan, Malayasia. 1976;93-104.
9. Rajbhar YP, Singh SD, Lal M, Singh G, Rawat PL. Performance of high density planting of Mango (*Mangifera indica* L.) under mid-Western plain zone of Uttar Pradesh. Int. J. Agri. Sci. 2016;12(2):298-301.
10. Osei-Bonsu K, Opoku-Ameyaw KK, Amoah FM, Oppong FK. Cacao-coconut intercropping in Ghana: Agronomic and economic perspectives. Agrofor. Syst. 2002;55:1–8.
11. Bismark MB. Effect of watering regime and cocoa pod husk on soil fertility and growth of hybrid cocoa seedlings in the semi - deciduous forest zone of Ghana. M.Sc. Thesis, Kwame Nkrumah University of Science and Technology, Kumasi; 2011.
12. Yadava UL. A rapid and nondestructive method to determine cholorophyll intact leaves. Hort. Sci. 1986;21(6):1148-1150.
13. Baihaqi S, Mahumad IL, Nelson SPC, Lockwood R. An evaluation of 22 clones at two locations each with three planting densities in Indonesia. In: International Workshop on Cocoa Breeding for Improved Production Systems. 2003;160-170.
14. Addae SAMUEL. Effect of different growth media on growth, survival rate and seedling vigour of cocoa (*Theobroma cacao*) (Doctoral dissertation, University of Education Winneba); 2022.
15. Koko LK, Didier S, Tacra TL, Assiri AA. Cacao-fruit tree intercropping effects on cocoa yield, plant vigour and light interception in Coˆte d'Ivoire. Agrofor; 2013.
16. Utomo B, Prawoto AA, Bonnet S, Bangviwat A, Gheewala SH. Environmental performance of cocoa production from monoculture and agroforestry systems in Indonesia. Journal of Cleaner Production. 2016;134:583-591.
17. Triadiati S, Tjitrosemito E, Sudarsono G, Qayim I, Leuschner C. Litterfall production and leaf litter decomposition at natural forest and cocoa agroforestry in Central Sulawesi, Indonesia. Asian J. Biol. Sci; 2011. ISSN 1996-3351.
DOI: 10.3923/ajbs.2011
18. Slattery RA, Walker BJ, Weber AP, Ort DR. The impacts of fluctuating light on crop performance. Plant physiology. 2018;176(2):990-1003.
19. Ewel J, Benedict F, Cory B, Becky B. Leaf area, light transmission, roots and leaf damage in nine tropical plant communities. Agro-Ecosystems. 1982;7:305-326.
20. De Bock A, Belmans B, Vanlanduit S, Blom J, Alvarado-Alvarado AA, Audenaert A. A review on the leaf area index (LAI) in vertical greening systems. Building and Environment. 2023;229:109926.
21. Asomaning EJA, Kwakwa RS, Hutcheon WV. Physiological studies on an Amazon shade and fertilizer trial at the cocoa research institute of Ghana. Ghana J. Agric. Sci. 1971;4:47-64.
22. Lewis VR, Farrell AD, Umaharan P, Lennon AM. Genetic variation in high light responses of Theobroma cacao L. accessions. Heliyon. 2021;7(6).
23. Mena-Montoya M, García-Cruzatty LC, Cuenca-Cuenca E, Pinargote LDV, Villamar-Torres R, Jazayeri SM. Pollen flow of *Theobroma cacao* and its relationship with climatic factors in the central zone of the Ecuadorian littoral. Bioagro. 2020;32(1):39-48.
24. Babatunde AK, Samuel A, Peter AO. Effects of organic amendments on growth, establishment and yield of cacao (*Theobroma cacao* L) in Southwestern Nigeria. Asian Research Journal of Agriculture. 2019;11(2):1–14.
Available:https://doi.org/10.9734/arja/2019/v11i230052

25. Khan MAH, Rahman MM, Tasmima T, Sultana N. Effect of fertilizer doses on turmeric at madhupur tract under AEZ-28. Asian Journal of Agricultural and Horticultural Research. 2023;10(4):507–515.
Available:https://doi.org/10.9734/ajahr/2023/v10i4290
26. Bai SH, Trueman SJ, Nevenimo T, Hannet G, Bapiwai P, Poienou M, Wallace HM. Effects of shade-tree species and spacing on soil and leaf nutrient concentrations in cocoa plantations at 8 years after establishment. Agriculture, ecosystems & environment. 2017 Aug 1;246: 134-43.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/117889