Original Research Article

ASSESSMENT OF VEGETATIVE AND FLOWER CHARACTERS IN COCOA (*Theobroma cacao*) UNDER DIFFERENT PLANTING DENSITIES

Abstract

An experiment was conducted to investigate the impact of planting density on vegetative and flowering characteristics of cocoa (Theobroma cacao) during its initial growth stage at the Coconut Farm of the Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore. Utilizing a Randomized Block Design (RBD) with eight treatments replicated three times, the study aimed to explore the influence of different spacing levels on plant morphology and flowering traits. The results delineated clear patterns across the spacing treatments. T1 (3m x 1.2m) showcased the tallest trees and the highest first branching height, indicating that wider spacing promotes vertical growth and higher branching points. T6 (2m) displayed the widest stem girth, suggesting that moderate spacing enhances stem development. T5 (1.5m) exhibited the highest number of fan branches, implying that denser planting encourages more lateral branching. Regarding flowering, T8 (3m) demonstrated the greatest number of flowers per cushion and per tree, highlighting the positive effect of wider spacing on flower production. T7 (2m) recorded the highest number of flower cushions per tree, indicating that optimal spacing can maximize the number of flowering sites. Notably, T6 (2m) boasted the highest pod set percentage at 0.98%, suggesting that a 2m spacing is beneficial for fruit setting efficiency. In conclusion, the study demonstrates that planting density significantly influences both vegetative growth and flowering characteristics in cocoa during the initial stages of crop growth. Wider spacings, such as those in T1 and T8, tend to promote taller trees and higher flower production, while moderate spacing like T6 enhances stem girth and pod set percentage. These findings underscore the importance of careful consideration of planting density to optimize both vegetative and reproductive performance in cocoa cultivation.

Keywords: Cocoa, spacing, growth, flower, pod set

Introduction

Cocoa, native to the Amazon region, is a significant plantation crop belonging to the genus Theobroma in the Malvaceae family(Alba et al., 2021). It thrives in the humid tropics between 20º N and 20º S, best at 300m above sea level, with an annual precipitation of 1500-2000mm and temperatures of 15-39°C(Goradevaishali, 2015). High humidity is essential for its growth. T. cacao is the only cultivable species among over 20 in the genus. Cultivation began in India in the early 1970s, mainly in South India, particularly Kerala. Globally, cocoa demand is rising, with an estimated additional one million metric tonnes needed by 2030. Cocoa is primarily cultivated for chocolate production, and its by-products find use in various industries. It's a small, cross-pollinated tree, growing up to 8-12m, with simple, shiny, dark green leaves. Flowers are small, yellowish-white to pale pink, cauliflorous, and self-incompatible. The fruit is an indehiscent drupe (pod) containing 20-60 seeds surrounded by sweet mucilage (Afoakwa, 2014).

In the 1980s, High Density Planting (HDP) technology was developed by the Ministry of Agriculture, Land and Marine Resources (MALMR) as an alternative to traditional Low Density Planting (LDP) systems (Kamaldeo et al., 2003). HDP aims to achieve earlier cropping, consistent high yields, and improved farm management practices, leading to increased productivity and profitability. It seeks to maximize yield per unit area of land (Ladaniya*et al*., 2020; Anthony and Minas., 2021)(Cortes and Perez, 1986). While HDP may result in lower yield per plant, the overall yield is significantly higher due to a larger plant population(Olufemi*et al*., 2020) (Armstrong, 1976). The primary goal of HDP is to enhance productivity and sustainability within limited land resources (Rajbhar et al., 2016).

In cocoa cultivation, HDP involves planting double rows of cocoa plants between two rows of coconut trees(Pauwels, 2016). Early-stage plant training to develop a compact canopy and regular pruning are essential for canopy structure and health, promoting better early canopy formation and creating a favorable microclimate. Nutrient management is crucial, as standard fertilizer doses may lead to reduced yields. Properly arranged high density cocoa within widely spaced coconut trees has been suggested as a profitable intercrop system for adoption by cocoa farmers, particularly in Ghana (OseiBonsu et al., 2002). With this objective, an experiment titled "Effect of planting density on vegetative and flower characters during initial stage of crop " has been initiated in Tamil Nadu.

The objectives of the experiment is to study the effect of different spacing levels on vegetative and flower characters during initial stage of crop.

Materials and methods

The study titled " Effect of planting density on vegetative and flower characters during initial stage of crop " was carried out at the Department of Spices and Plantation Crops, Horticultural College and Research Institute, a part of the Tamil Nadu Agricultural University located in Coimbatore, Tamil Nadu. The research spanned over a year, focusing on cocoa trees planted using high-density techniques at the Coconut Farm in Coimbatore. Vegetative and flower characters of the cocoa trees were assessed during two distinct seasons: July to December and January to June. The variety was Forestero.

Table 1.

Experimentaldetails

Design	:	RBD
Treatments	:	Eight
Replications	:	Three
Ageof thecrop	:	4years

Table 2. Treatmentdetails

Treatment	**Details**
Doublerowofcocoabetween two coconut rows	
T1	3m x1.2m
T2	3mx2m
T3	3m x2.5m
T4	3m x3m
Singlerow of cocoabetween two coconutrows	
T5	1.5m
T6	2m
T7	2.5m
T8	3m

Observations recorded

Tree height, first branching height, stem girth, and the number of fan branches were measured to assess the growth characteristics of cocoa trees under different spacing conditions across two seasons. Tree height was determined by measuring from the ground to the canopy tip, while first branching height was measured from ground level to the first jorquette point. Stem girth was recorded at 15 cm above the ground. The number of fan branches emerging from the first jorquettewas also counted. Flower characteristics, including flower numbers per cushion, flower cushion numbers per tree, flower number per tree, and pod set percentage, were evaluated to understand the reproductive performance of cocoa trees. Flower numbers per cushion were determined by selecting twenty random flower cushions within marked areas on the main trunk and fan branches. The mean number of flowers per cushion was calculated. The total number of flower cushions per tree and the resulting flower number per tree were recorded. Additionally, pod set percentage was calculated using a specific formula considering various factors affecting pod development. This comprehensive assessment provides insights into the growth and reproductive behavior of cocoa trees under different spacing conditions, facilitating informed agricultural practices for improved yield and quality.

Results and discussion

In Season I (July to December), significant differences were observed in tree height among the eight different spacings studied for cocoa. 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. The highest height was again observed in T1 (3m x 1.2m), while the lowest was in T7 (2.5m). Regarding first branching height, significant differences were noted in both seasons. In Season I, the maximum height (0.87m) was recorded in T1 (3m x 1.2m), whereas T4 (3m x 3m) registered the minimum jorquette height (0.60m). Similarly, in Season II, T1 (3m x 1.2m) recorded the maximum height (1.05m), while T8 (3m) had the lowest height (0.85m), statistically comparable to T2 (3m x 2m) and T4 (3m x 3m) with heights of 0.89m and 0.87m, respectively.Stem girth was significantly influenced by spacing in both seasons, 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).

Table3.Effectofdifferentspacingontreeheightfordifferentseasonsin cocoa

Treatment	Treeheight(m)		
	SeasonI	**SeasonII**	**Mean**
T1– 3m x1.2m	2.24	2.42	2.33
T2– 3mx2m	1.55	2.04	1.80
T3– 3m x2.5m	1.68	1.75	1.71
T4-3m x3m	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– Julyto December	SeasonII-JanuarytoJune

Table 4. Effect of different spacing on first branching height for differentseasons in cocoa

Treatment	Firstbranching height(m)		
	SeasonI	**SeasonII**	**Mean**
T1– 3m x1.2m	0.87	1.05	0.96
T2– 3mx2m	0.75	0.89	0.82
T3– 3m x2.5m	0.63	0.91	0.77
T4-3m x3m	0.60	0.87	0.73
T5-1.5m	0.81	0.99	0.90
T6– 2m	0.70	0.95	0.82
T7-2.5m	0.76	1.03	0.89
T8– 3m	0.76	0.85	0.80
Mean	**0.73**	**0.94**	
SE(d)	**0.018**	**0.023**	
CD(0.05)	**0.039****	**0.049****	

Morphological characteristics such as plant height, first branching height, stem girth, and the number of fan branches play pivotal roles in determining cocoa canopy architecture. These traits exhibited significant disparities under different spacing conditions. In this study, T1 (3m x 1.2m) consistently displayed the highest tree height and first branching height across both seasons investigated (July to Decemberand January to June). The heightened tree height observed in high planting densities could be attributed to the inherent tendency of plants to exhibit vertical growth in response to mutual shading. High Density Planting (HDP) practices tend to restrain tree size (Kumar *et al*., 2021), promoting a favorable allocation of assimilates between reproductive and vegetative parts (Mooleedhar, 1991). However, in contrast, stem girth reached its maximum in plants subjected to low planting densities. This finding aligns with Baihaqi et al. (2003), who noted that cocoa clones exhibit greater vigor and girth when grown at lower planting densities, as cocoa plants respond positively to increased light exposure. Wood (1964) similarly concluded that a spacing of 3m*2 m is optimal for vigorous cocoa seedling types. Additionally, Koko (2013) highlighted that intercropped cocoa trees tend to exhibit significantly smaller stature compared to monocropped counterparts. This evidence underscores the intricate relationship between planting density, morphological traits, and cocoa growth dynamics, shedding light on optimal cultivation practices for enhanced productivity and quality.

Table 5. Effect of different spacing on stem girth and number of fan branches for different seasons in cocoa

Treatment	Stemgirth (cm)			Numberoffan branches
	SeasonI	**SeasonII**	**Mean**	
T1– 3m x1.2m	11.36	11.56	11.46	3.85
T2– 3mx2m	13.30	14.23	13.76	4.57
T3– 3m x2.5m	13.28	14.33	13.80	4.43
T4-3m x3m	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****

In Season I (July to December), significant variations were observed in the number of flowers per cushion among the different spacings studied for cocoa. The maximum number of flowers per cushion (8.66) was recorded in T8 (3m), while the minimum (5.08) was observed in T1 (3m x 1.2m), which was comparable to T2 (3m x 2m) with 5.17 flowers per cushion. For Season II (January 2017 to June 2017), T8 (3m) exhibited the highest number of flowers per cushion (8.91), whereas the lowest was recorded in T3 (3m x 2.5m) with 5.01 flowers per cushion. Regarding the number of flower cushions per tree, significant differences were noted in both seasons. In Season I, the highest number of cushions per tree (1879.17) was observed in T7 (2.5m), followed by T3 (3m x 2.5m) with 1646.82, while the lowest (1332.46) was recorded in

T2 (3m x 2m). Similarly, in Season II, T7 (2.5m) again exhibited the highest number of cushions per tree (1943.63), whereas the lowest (1408.11) was observed in T1 (3m x 1.2m).

Table 6. Effect of different spacing on number of flowers per cushion for different seasons in cocoa

Treatment	Numberof flowers per cushion		
	SeasonI	SeasonII	Mean
T1– 3m x1.2m	5.08	5.29	5.18
T2– 3mx2m	5.17	5.50	5.33
T3– 3m x2.5m	5.82	5.01	5.41
T4-3m x3m	7.69	7.51	7.60
T5-1.5m	6.58	6.33	6.45
T6– 2m	7.87	7.99	7.93
T7-2.5m	6.61	5.43	6.02
T8– 3m	8.66	8.91	8.78
Mean	**6.68**	**6.49**	
SE(d)	**0.126**	**0.170**	
CD(0.05)	**0.271****	**0.364****	

Significant variations were also observed in the number of flowers per tree among different spacings in both seasons. In Season I, the maximum number of flowers per tree (13455.82) was observed in T8 (3m), while the minimum (6888.81) was in T2 (3m x 2m). For Season II, the highest number of flowers per tree (14164.49) was noticed in T8 (3m), whereas the lowest (7448.90) was observed in T1 (3m x 1.2m). Pod set was significantly affected by different spacings in both seasons. In Season I, the highest pod set (1.02 per cent) was recorded in T6 (2m), while the lowest (0.42 per cent) was in T1 (3m x 1.2m). Similarly, in Season II, T6 (2m) exhibited the highest pod set (1.03 per cent), while the lowest (0.50 per cent) was observed in T1 (3m x 1.2m), comparable to T8 (0.84 per cent).

Table 7. Effect of different spacing on number of flower cushions per tree for different seasons in cocoa

Treatment	Numberof flowercushionspertree		
	SeasonI	SeasonII	Mean

T1– 3m x1.2m	1371.31	1408.11	1387.88
T2– 3mx2m	1332.46	1415.52	1364.79
T3– 3m x2.5m	1646.82	1701.47	1534.79
T4-3m x3m	1427.24	1528.22	1415.01
T5-1.5m	1429.58	1534.81	1424.14
T6– 2m	1462.90	1492.90	1443.99
T7-2.5m	1879.17	1943.63	1813.29
T8– 3m	1553.79	1589.73	1610.40
Mean	**1512.90**	**1576.79**	
SE(d)	**36.60**	**22.06**	
CD(0.05)	**78.52****	**47.33****	

Flowering in cocoa is intricately influenced by a multitude of factors encompassing climate, environmental conditions, tree age, spacing, and the availability of nutrients and moisture. In the current investigation, flowering characteristics such as the number of flowers per cushion, the number of flowers per tree and pod setwere notably impacted by varying spacing regimes. The highest count of flowers per cushion and per tree was observed in T8 (3m), attributed to the maximum light interception afforded by its wider spacing. This finding aligns with Sale (1970), who established a positive correlation between light intensity and cocoa flowering(da Silva Branco et al., 2017). Similarly, reports by Lachenaud and Mossu (1985), and Peavey *et al*., 2020 suggested that heightened light exposure promotes flowering while reducing premature fruit drop. Furthermore, Govindaraj (2012) emphasized the critical role of maintaining optimal canopy architecture to enhance light interception and stimulate flowering induction in cocoa(Tostoet al., 2022, Tosto et al., 2023). These insights underscore the pivotal influence of spacing on cocoa flowering dynamics, underscoring the significance of appropriate cultivation practices for optimizing yield and quality.

Table 8. Effect of different spacing on number of flowers per tree for different seasons in cocoa

Treatment	**Numberofflowerspertree**		
	SeasonI	**SeasonII**	**Mean**
T1– 3m x1.2m	6966.25	7448.90	7106.18
T2– 3mx2m	6888.81	7785.36	7135.06

T3– 3m x2.5m	9584.49	8524.36	8651.89
T4-3m x3m	10975.47	11476.93	9383.33
T5-1.5m	9406.63	9049.24	8592.10
T6– 2m	11513.02	11928.27	9650.16
T7-2.5m	12421.31	10553.91	10575.13
T8– 3m	13455.82	14164.49	11024.19
Mean	**10151.47**	**10116.43**	
SE(d)	**237.33**	**195.67**	
CD(0.05)	**509.09****	**419.72****	

Table 9. Effect of different spacing on pod set for different seasons in cocoa

Treatment	**Podset(percent)**		
	SeasonI	**SeasonII**	**Mean**
T1– 3m x1.2m	0.42	0.50	0.45
T2– 3mx2m	0.91	0.94	0.71
T3– 3m x2.5m	0.62	0.72	0.57
T4-3m x3m	0.75	0.76	0.86
T5-1.5m	0.61	0.87	0.76
T6– 2m	1.02	1.03	0.98
T7-2.5m	0.58	0.83	0.66
T8– 3m	0.76	0.84	0.73
Mean	**0.70**	**0.81**	
SE(d)	**0.01**	**0.02**	
CD(0.05)	**0.03****	**0.04****	

Conclusion

Observations on plant morphological traits highlighted distinct trends across different spacing treatments. Notably, T1 (3m x 1.2m) exhibited the tallest trees (2.33m) and the highest first branching height (0.96m), indicative of favorable growth conditions within this spacing arrangement. Stem girth reached its maximum (16.82cm) in T6 (2m), while T5 (1.5m) boasted the highest number of fan branches (4.87), suggesting variations in canopy development and structural integrity among the treatments. Regarding flower characteristics, T8 (3m) emerged as the leader, showcasing the highest number of flowers per cushion (8.78) and per tree (11024.19). Surprisingly, T7 (2m) outshone other treatments in terms of the number of flower cushions per tree, recording a remarkable count of 1813.29. Moreover, the pod set percentage peaked at 0.98 per cent in the 2m spacing (T6), underscoring the impact of spacing on reproductive outcomes in cocoa cultivation. These findings underscore the importance of spacing management in optimizing both morphological and reproductive parameters, thereby enhancing overall cocoa productivity and quality.

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