

*Original Research Article*

**EFFECT OF DIFFERENT PLANTING DENSITY IN COCOA (*Theobroma cacao L.*)  
ON LEAF MACRO AND MICRONUTRIENT LEVELS GROWN UNDER COCONUT  
ECOSYSTEM**

**Abstract**

An experiment investigating the impact of different cocoa densities on leaf macro and micronutrient levels within a coconut ecosystem was conducted at the Coconut Farm of the Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore. The study employed a Randomized Block Design (RBD) comprising eight treatments, each replicated three times. Notably, among the various spacing configurations, T1 (3m x 1.2m) exhibited the highest levels of leaf nitrogen (1.86%), phosphorus (0.084%), potassium (1.39%), and boron (91.33 ppm) content. This suggests that under Tamil Nadu conditions, high-density planting in the T1 treatment not only resulted in elevated nutrient levels but also correlated with a notable increase in revenue. These findings underscore the potential benefits of adopting high-density planting practices in cocoa cultivation within coconut ecosystems. Further research is warranted to explore the long-term implications of spacing configurations and nutrient interactions on crop productivity and profitability.

**Keywords:** Cocoa, spacing, macro and micro nutrients

**Introduction**

Cocoa, originating from the Amazon region, serves as a vital cash crop in the humid tropics spanning from 20° N to 20° S of the equator (Goradevaishali, 2015). Its optimal growth conditions include an elevation of approximately 300 meters above sea level, with an annual rainfall of 1500-2000 mm and temperatures ranging from 15-39°C. Adequate humidity levels are crucial for its cultivation. While the *Theobroma* genus comprises over 20 species, only *T. cacao* is commercially grown. In India, cocoa farming commenced in the 1970s, primarily in South India, notably Kerala, where it is commonly intercropped with coconut. Kerala dominates the cocoa cultivation scenario, contributing to 76% of the area and 78% of total production, while Karnataka and Tamil Nadu also partake in cocoa cultivation.

High density planting (HDP), developed in the 1980s by the Ministry of Agriculture, Land and Marine Resources (MALMR), is an alternative to low density planting (LDP) systems, aiming to optimize yield per unit area of land (Olufemi *et al.*, 2020) (Kamaldeo *et al.*, 2003; Cortes and Perez, 1986). Despite lower yields per plant, HDP leads to significantly higher cumulative yields due to a larger plant population (Armstrong, 1976). The main goal of HDP is to increase

productivity and profitability while addressing shrinking land-holdings and promoting sustainable agricultural practices (Rajbhar et al., 2016; Tripathi et al., 2020; Ladaniya et al., 2020; Anthony and Minas., 2021)).

Osei Bonsu et al. (2002) propose a profitable intercrop system for cocoa farmers in Ghana by implementing high density planting techniques. This method involves planting double rows of cocoa plants between coconut rows. Early plant training for compact canopy development, followed by regular pruning to maintain canopy structure and health, is essential. This approach encourages better early canopy formation and establishes a microclimate environment. Nutrient management is crucial, as standard fertilizer doses may result in low yields. Properly arranged high density cocoa within widely spaced coconut trees is suggested to enhance productivity and profitability. With this aim, the experiment on “Effect of different density in cocoa on leaf macro and micro nutrient levels grown under coconut ecosystem” in Tamil Nadu has been initiated. The objectives of the experiment to study effect of different density in cocoa on leaf macro nutrients such as N, P and K and micro nutrient such as boron, zinc and iron.

**Materials and methods**

The study titled "Impact of varied cocoa densities on leaf macro and micronutrient content within coconut farming settings" was carried out at the Department of Spices and Plantation Crops, Horticultural College and Research Institute, Tamil Nadu Agricultural University, located in Coimbatore, Tamil Nadu. The variety used in this study was Forastero.

**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

### Nutrient analysis

Leaf nitrogen, phosphorus, and potassium levels were analyzed using various methods for samples collected from cocoa trees grown under different spacing conditions. Total nitrogen content in leaf blades and petioles was determined using the Microkjeldahl method (Goyalet *al.*, 2022;(Humphries, 1956) and reported as a percentage. Phosphorus levels in leaf samples were measured in a triple acid extract using a colorimetric method (Balaet *al.*, 2019; Jackson, 1967) and expressed as a percentage. Potassium content in leaf and petiole samples was assessed from the triple acid extract using a Flame Photometer ((Balaet *al.*, 2019; Jackson, 1973) and values were reported as a percentage. The concentrations of these major leaf nutrients were categorized according to Wessel (1971) to differentiate between normal and deficient cocoa leaves.

**Table 3.** Range of macro nutrients

Nutrient	CriteriaaccordingtoLoue(1961)			CriteriaaccordingtoMurray(1967)		
	Normal	Moderately deficient	Severely deficient	Normal	Moderately deficient	Severely deficient
N(%)	2.35-2.50	1.80-2.00	<1.80	>2.00	1.80-2.00	<1.80
P(%)	>0.18	0.10-0.13	0.08-0.10	>0.20	0.13-0.20	<0.13
K(%)	>1.20	1.00-1.20	<1.00	>2.00	1.20-2.00	<1.20

Leaf zinc, iron, and boron levels were assessed using various methods for samples collected from cocoa trees grown under different spacing conditions. Total zinc and iron content in leaf blades and petioles were determined from the triple acid extract using an atomic absorption spectrophotometer (Balaet *al.*, 2019; Jackson, 1967) and expressed in parts per million (ppm). Total boron content in leaf blade and petiole samples was estimated using the caramine method (Hatcher and Wilcox, 1950) and expressed in ppm. The concentrations of these minor leaf nutrients were categorized according to de Geus (1973) to distinguish between normal and deficient cocoa leaves.

**Table 4.** Range of micronutrients

<b>Nutrient</b>	<b>Normalrange(ppm)</b>	<b>Deficiencyrange(ppm)</b>
Fe(Iron)	65-175	50
Zn(Zinc)	30-65	15-20
B(Boron)	25-75	8.5-11

### **Statistical analysis**

The results of the experiment were statistically analyzed by adopting the procedures suggested by Panse and Sukhatme (1961).

### **Results and discussion**

The study underscores significant variations in leaf nutrient content across diverse spacing treatments, providing crucial insights into the impact of spacing on cocoa plant nutrition. Table 5 and Fig1. denotes the effect of different spacing in cocoa on Nitrogen, Phosphorous and Potassium.

Notably, T1 (3m x 1.2m) emerges as the optimal spacing configuration, displaying the highest nitrogen content at 1.86%, closely followed by T2 (3m x 2m) at 1.79%, highlighting the pivotal role of spacing in nitrogen assimilation efficiency. Furthermore, phosphorus content exhibited notable disparities, with T1 registering the highest (0.084%) and T7 (2.5m) the lowest (0.032%), emphasizing the profound influence of spacing on phosphorus uptake. The potassium content also varied significantly among spacing treatments, with T1 showcasing the highest (1.39%) and T7 the lowest (0.86%), indicating the critical importance of spacing in potassium acquisition.

**Fig 1.**Effect of different spacing in cocoa on Nitrogen, Phosphorous and Potassium

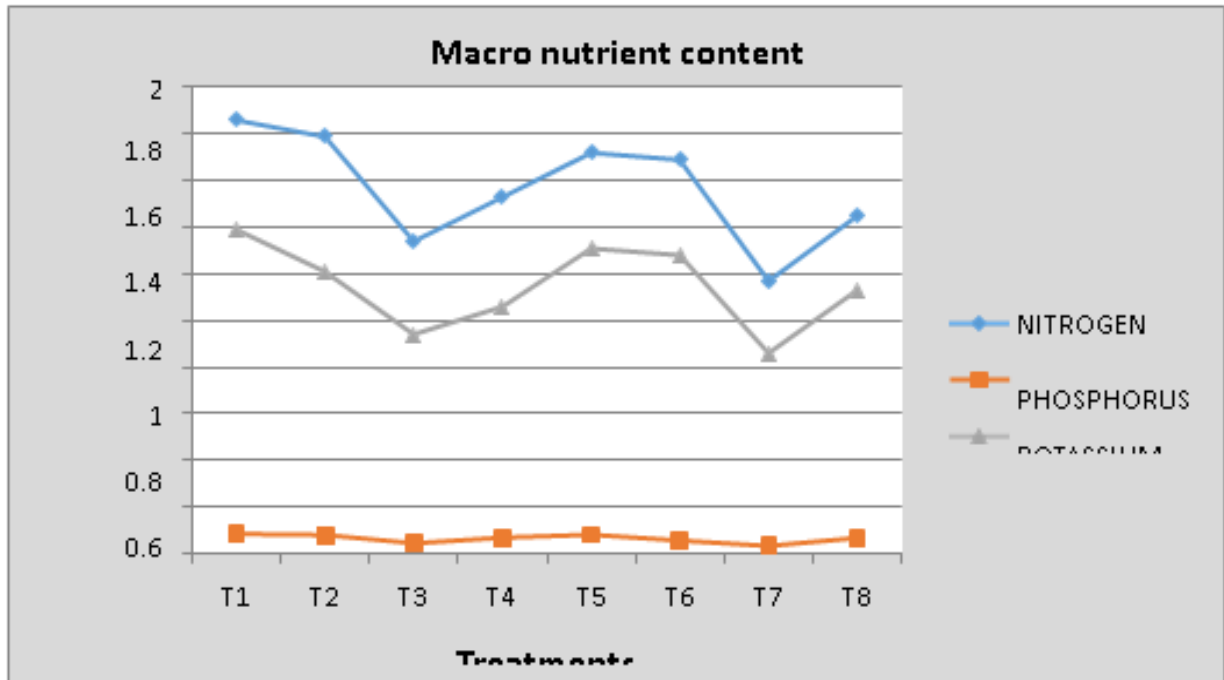


Table 6 depicts the effect of different spacing in cocoa on Boron, Iron and Zinc. Additionally, boron content was substantially elevated in T1 (91.33 ppm) compared to T7 (44.71 ppm), underscoring the intricate relationship between spacing and micronutrient availability. Furthermore, iron content peaked in T2 (306.62 ppm) and zinc content in T2 as well (321.64 ppm), elucidating the crucial role of spacing in facilitating essential micronutrient uptake in cocoa leaves. These findings accentuate the imperative of optimal spacing management practices to enhance nutrient absorption efficiency and ultimately boost cocoa yield and quality.

**Table 5.** Effect of different spacing in cocoa on Nitrogen, Phosphorous and Potassium

Treatment	Nitrogen(%)	Phosphorous (%)	Potassium(%)
T1– 3m x 1.2m	1.86	0.084	1.39
T2– 3mx2m	1.79	0.079	1.21
T3– 3m x2.5m	1.34	0.043	0.94
T4-3m x3m	1.53	0.067	1.06
T5-1.5m	1.72	0.081	1.31

T6- 2m	1.69	0.055	1.28
T7-2.5m	1.17	0.032	0.86
T8- 3m	1.45	0.066	1.13
<b>Mean</b>	<b>1.56</b>	<b>1.14</b>	<b>1.14</b>
<b>SE(d)</b>	<b>0.03</b>	<b>0.02</b>	<b>0.01</b>
<b>CD(0.05)</b>	<b>0.069**</b>	<b>0.049**</b>	<b>0.040**</b>

**\*\* -Highly significant**

The analysis of leaf samples reveals significant disparities in nutrient status among different spacing treatments. Notably, T1 (3m x 1.2m) exhibited the highest percentages of nitrogen, phosphorus, and potassium indicating superior nutrient uptake efficiency in closely spaced trees. However, this heightened nutrient status in tighter spacing configurations may necessitate increased inputs for sustained productivity in the long term, as highlighted by Alex and Valle (2008); Van Vliet and Giller, 2017. In terms of micronutrients, T2 (3m x 2m) showcased the maximum zinc and iron content crucial for chlorophyll synthesis, essential for photosynthesis and overall plant vigor. Conversely, boron content, pivotal for crop yield, was notably elevated in T1 (3m x 1.2m). These findings suggest the positive influence of micronutrients like iron, zinc, and boron on various physiological functions, potentially enhancing tree yield and pod quality, as emphasized by Shoeib and El sayed (2003) Yatsenkoet al., 2020; Van Vliet and Giller,2017).

**Table 6. Effect of different spacing in cocoa on Boron, Iron and Zinc**

<b>Treatment</b>	<b>Boron(ppm)</b>	<b>Iron(ppm)</b>	<b>Zinc (ppm)</b>
T1- 3m x1.2m	91.33	297.48	202.29
T2- 3mx2m	86.48	306.62	321.64
T3- 3m x2.5m	53.36	192.78	213.00
T4-3m x3m	69.82	211.55	205.60
T5-1.5m	82.57	273.37	237.90

T6– 2m	61.65	124.70	119.87
T7-2.5m	44.71	156.56	151.91
T8– 3m	75.24	249.12	224.20
<b>Mean</b>	<b>70.64</b>	<b>226.52</b>	<b>209.55</b>
<b>SE(d)</b>	<b>1.28</b>	<b>5.25</b>	<b>3.96</b>
<b>CD(0.05)</b>	<b>2.75**</b>	<b>11.27**</b>	<b>8.50**</b>

**\*\* -Highly significant**

## Conclusion

The analysis of leaf macronutrient content across varying crop spacing configurations revealed notable disparities. T1 (3m x 1.2m) consistently exhibited the highest values for leaf nitrogen (1.86%), leaf phosphorus (0.084%), and leaf potassium (1.39%) content, underscoring the significance of spacing in nutrient uptake efficiency. Furthermore, the examination of micronutrient content in cocoa leaves across different spacing levels unveiled significant findings. T1 (3m x 1.2m) emerged with the highest boron content at 91.33 ppm, highlighting its critical role in cocoa plant development. Additionally, T2 (3m x 2m) demonstrated maximum iron and zinc content at 124.70 ppm and 321.64 ppm, respectively, emphasizing the importance of adequate spacing in facilitating optimal micronutrient uptake. These findings underscore the pivotal role of spacing management strategies in optimizing both macro and micronutrient assimilation in cocoa cultivation, thereby contributing to enhanced yield and quality. It's important to note that this finding is preliminary, given that the field trial was conducted during the initial years of establishment. Further field trials are warranted in subsequent years to comprehensively assess the impact of spacing and plant interaction. Additionally, factors such as crop age, competition effects, and resource management efficiency of cocoa and coconut under different spacing configurations are crucial considerations before the widespread adoption of high-density planting technology.

## Reference

1. Alex-Alan, F. d. A and R. R. Valle. 2008. Ecophysiology of the cacao tree. **Braz. J. Plant., 19(4):** 425-448.
2. Anthony, B. M., & Minas, I. S. (2021). Optimizing peach tree canopy architecture for efficient light use, increased productivity and improved fruit quality. *Agronomy, 11(10)*, 1961.
3. Armstrong, K.B. 1976. A spacing trial with single and multiple stem cocoa. **In:** Proc. of the Seminar on Cocoa and Coconuts, Taiwan, Malaysia., pp. 93-104.

4. Bala, R., Kalia, A., & Dhaliwal, S. S. (2019). Evaluation of efficacy of ZnO nanoparticles as remedial zinc nanofertilizer for rice. *Journal of Soil Science and Plant Nutrition*, 19, 379-389.
5. Cortes, S. and A. Perez. 1986. Influence of high planting densities on yields and bean quality. **In:** Min. of Agric. Lands and Marine Resources, Trinidad., **4(2):** 29-39.
6. De Geus, J. G. 1973. Fertilizer Guide for the Tropics and Subtropics. Zurich: Centre d'Etudedel'Azote. Wessel, M. 1971. Fertiliser requirements of cacao (*Theobroma cacao*) in South Western Nigeria. Communication 61. **Dept. of Agric. Res., Royal Trop, Inst., Amsterdam.**
7. Goradevaishali, S. (2015). *Identification of molecular marker for self-incompatibility in selected germplasm accessions of cocoa (Theobroma cacao L.)* (Doctoral dissertation, College of Horticulture, Vellanikkara).
8. Goyal, K., Singh, N., Jindal, S., Kaur, R., Goyal, A., & Awasthi, R. (2022). Kjeldahl method. *Advanced Techniques of Analytical Chemistry, 1*, 105-112.
9. Hatcher, J. T and L. V. Wilcox. 1950. Colorimetric determination of boron using carmine. **Anal. Chem., 22:**567-569.
10. Humphries, K. C. 1956. Mineral components and analysis. **In:** Modern methods of plant analysis (Eds.) Paech, K. and M.O. Tracy. Springer Verlag, Berlin, **pp:** 468-502.
11. Jackson M. L. 1967. Soil Chemical analysis. Prentice Hall, Inc. Englewood.
12. Jackson, M. L. 1973. Soil chemical analysis. Constable and Co. Ltd., London.
13. Kamaldeo, M., T. Indalsingh, D. Ramnath and A. Cumberbatch. 2003. High Density Planting of Cacao: The Trinidad and Tobago Experience. **In:** International Workshop on Cocoa Breeding for Improved Production Systems, Accra, Ghana., **pp:** 171-182.
14. Ladaniya, M. S., Marathe, R. A., Das, A. K., Rao, C. N., Huchche, A. D., Shirgure, P. S., & Murkute, A. A. (2020). High density planting studies in acid lime (*Citrus aurantifolia* Swingle). *Scientia Horticulturae*, 261, 108935.
15. Olufemi, A. K., Olatunde, F. A., Adewale, A. S., Mohammed, I., Osasogie, U., Efe, A. F., & Adeyemi, O. F. (2020). 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*, 8(1), 217-223.
16. Osei-Bonsu, K., K. K. Opoku-Ameyaw, F. M. Amoah and F. K. Opong. 2002. Cacao-coconut intercropping in Ghana: agronomic and economic perspectives. **Agrofor. Syst., 55:**1-8.
17. Panse, V. G and P.V. Sukhatme. 1961. "Statistical methods for agricultural workers," 2nd Edition ICAR, New Delhi, **pp:** 361.
18. Rajbhar, Y.P., S.D. Singh, M. Lal, G. Singh and P.L. Rawat. 2016. Performance of high density planting of Mango (*Mangifera indica* L.) under mid-Western plain zone of Uttar Pradesh. **Int. J. Agri. Sci., 12[2]:** 298-301.
19. Shoeib, M. M and A. El sayed. 2003. Response of "Thompson Seedless" grape vines to the spray of some nutrients and citric acid. **Minia J. Agric. Res.Dev., 23(4):** 681-698.
20. Tripathi, V. K., Kumar, S., Dubey, V., & Nayyer, M. A. (2020). High-Density Planting in Fruit Crops for Enhancing Fruit Productivity. In *Sustainable Agriculture* (pp. 253-267). Apple Academic Press.
21. Van Vliet, J. A., & Giller, K. E. (2017). Mineral nutrition of cocoa: a review. *Advances in agronomy*, 141, 185-270.
22. Wessel, M. 1971. Fertiliser requirements of cacao (*Theobroma cacao* L.) in South Western Nigeria. Communication 61. **Dept. of Agric. Res., Royal Trop, Inst:** Amsterdam.
23. Yatsenko, V., Ulianych, O., & Yanowsky, Y. (2020). Effect of iron, zinc and boron on the growth, physiological state, productivity and storability of *Allium Sativum* L. *Ukrainian Journal of Ecology*, 10(4), 33-42.

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