Influence of Varying Nitrogen Levels on Growth and Biomass Partitioning in Cocoa Varieties

ABSTRACT

Among the 17 vital plant nutrients, nitrogen (N) is crucial in crop production. It extensively enhances the growth and biomass production of plants by improving photosynthesis and protein synthesis. To study the impact of three different N levels (40, 80, and 120 ppm) on the growth and biomass production of eight cocoa varieties, a hydroponic experiment was carried out at ICAR-CPCRI, Regional Station, Vittal. The results showed that increasing N concentration significantly boosted growth and biomass production. Among the different varieties, VTLCH-1 exhibited the tallest plant height, maximum number of leaves, greater stem diameter, and the highest total fresh biomass when grown with high N levels. Biomass partitioning analysis revealed that higher Nlevels increased leaf and stem biomass while reducing root biomass, leading to a higher shoot-to-root ratio. This indicates that N application influences the overall biomass andbiomass distribution within the plant.

Keywords:*Cocoa, Nitrogen, Growth, Biomass partitioning*

Introduction

Cocoa (*Theobroma cacao* L.), native to the Amazon region, is a perennial plant of significant economic importance and one of the most widely traded agricultural commodities globally (Karpagalakshmi and Muthusamy, 2018). As with most crops, cocoa requires nitrogen (N) in the largest quantities (Harteminkand Donald, 2005). Nitrogen, often referred to as the “life element,” is essential in the composition of various metabolic and active substances in plants. Nitrogen deficiency can lead to weakened root growth, altered root structure, reduced plant biomass, and decreased photosynthesis (De Souza et al., 2007).

Nitrogen is the most limiting nutrient for crop production in many of thetropical soils, and its efficient use is important for the economic sustainabilityof cropping systems (Fageria and Baligar, 2005).Nitrogen additions stimulate the growth of young cocoa seedlings and jorquette formation, particularly in interaction with potassium (K) and magnesium (Mg) applications, thereby promoting early closure of the cocoa canopy (Wessel, 1971). High yield in cocoa is contingent upon optimal nitrogen levels, as Nsupports the vegetative phase, determining the number of cocoa pods produced during the generative stage (Kaba et al., 2018). Moreover, Nis crucial for developing the cocoa canopy and frame prior to pod production, thus enhancing overall growth (Ribeiro et al., 2008).

Previous studies, such as those conducted by Rieiro et al., have reported significant genotypic differences in the growth and biomass production of cocoa. Understanding these genotypic responses is crucial for optimizing nitrogen management strategies to enhance cocoa productivity and sustainability. The current study aims to address this gap by investigating the effect of different nitrogen levels on the growth, biomass production, and partitioning in cocoa seedlings. By examining these parameters at the eight-month stage, this research seeks to elucidate the interactions between nitrogen availability and genotypic variation in cocoa. The results of this study could provide valuable insights into developing genotype-specific nitrogen management practices, ultimately contributing to more efficient nutrient use and improved cocoa yields.Despite the recognized importance of N, the varietal differences in response to varying nitrogen doses remain underexplored. Therefore, this study aims to analyze the growth and biomass partitioning in different cocoa varieties subjected to three different nitrogen levels, providing valuable insights into optimizing nitrogen use for improved cocoa cultivation.

Materials and Methods

The experiment was conducted at the ICAR-Central Plantation Crops Research Institute (CPCRI), Regional Station, Vittal, during 2021-2022, in a glasshouse. The methodology followed was the same as described in an earlier study by Nayana et al. (2024), with the only difference being the nitrogen levels. At eight months, growth parameters such as plant height, number of leaves, and stem diameter were recorded. Subsequently, plants were removed from the nutrient solution, and the fresh weights of leaves, stems, and roots were measured. The plant parts were dried in a hot air oven at 65 □ until a constant weight was obtained. Biomass partitioning was determined by measuring the dry weight of different plant parts (roots, stems, leaves) and expressing each as a percentage of the total plant dry weight.

Statistical analysis

Data were subjected to analysis of variance (ANOVA) in a factorial design, considering two sources of variation: cocoa varieties and Nlevels. The significance of differences among the mean values was assessed at 5% significance level.

3. RESULTS AND DISCUSSION

3.1 Growth parameters

The growth parameters, viz. plant height, number of leaves, and stem diameter, varied significantly among different cocoa varieties, N levels, and their interactions. Nitrogen was found to have profound effect on the growth of cocoa varieties. Increasing N levels significantly increased all the growth parameters. Cocoa hybrid, VTLCH-1 recorded the highest plant height and number of leaves, significantly higher than all other varieties. Among the interactions, plants of VTLCH-1 grown with a high N level of 120 ppm recorded the highest plant height, number of leaves, and stem diameter (Table 1).

3.2 Biomass production and partitioning

Significant variations in biomass weight and partitioning were observed across different cocoa varieties, N levels, and their interactions.Higher N concentration in the nutrient solution significantly increased the fresh weight of leaves, stem, and the whole plant. However, root weight exhibited a declining trend with increasing N levels. Among the varieties, VTLCH-1 recorded the highest fresh weight of leaves, stem, roots, and the entire plant, significantly surpassing all other varieties. Among the interactions, VTLCH-1 grown at 120 ppm N recorded the highest values for fresh weight of leaves, stem, and the whole plant. In contrast, the highest root weight was observed in plants of VTLCH-1 grown at low N level (Table 2).

Significant variation in biomass partitioning to different parts was observed. Among different parts, biomass portioning to leaves was high. At low nitrogen level, biomass partitioning to roots was high, whereas, at high nitrogen level, biomass partitioning to leaves was high. Among the varieties, VTLCH-5 exhibited the highest partitioning to leaves, VTLCH-1 showed the highest partitioning to stem and VTLCS-2 had the highest partitioning to roots (Fig 1). Further, the biomass partitioning to different portions of the shoot was found to be significant. Among different parts of the shoot, the biomass partitioning to the middle shoot was high compared to the top and lower shoots. Among different N levels, biomass partitioning to top and lower shoots was highest at high N level, whereas the highest biomass partitioning to middle shoot was observed at medium N level. Among different varieties, VTLCH-2 recorded the highest biomass partitioning to the top shoot, VTLCH-3 recorded the highest biomass partitioning to the middle shoot and VTLCS-2 recorded the highest biomass partitioning to the lower shoot (Fig 2).

Additionally, significant variation in biomass partitioning ratios was observed among the different cocoa varieties and nitrogen levels. Cocoa hybrid, VTLCH-5 had the highest shoot-to-root ratio and shoot-to-fine root ratio, while VTLCS-2 recorded the highest root-to-leaf ratio (Table3). Regarding nitrogen levels, plants grown with high Nhad the maximum shoot-to-root ratio, while those grown with low Nhad the highest root-to-leaf ratioand shoot-to-fine root ratio. Considering the interaction between varieties and nitrogen levels, plants of VTLCH-1 grown with high nitrogen had the highest shoot-to-root ratio, while VTLCH-4 grown with low nitrogen had the lowest. In contrast, the highest root-to-leaf ratio was observed in VTLCH-4 grown with low nitrogen and the lowest in VTLCH-1 grown with high nitrogen. The highest shoot-to-fine root ratio was recorded in VTLCH-2 grown with low nitrogen and the lowest in VTLCH-3 grown with high nitrogen (Table 3).

Discussion

Nitrogen application encourages cell division, chlorophyll content, and photosynthesis, leading to increased biomass accumulation and more extensive foliage (Barker, 1974). Additionally, the regulatory role of N in fundamental growth processes, including hormonal balance and enzyme activity, significantly enhances growth parameters (Crozier et al., 1999). N helps in protein synthesis, a crucial factor in cell division and growth, resulting in increased biomass accumulation (Chen et al., 2017). Ribeiro et al. (2008) also reported increased biomass production with increasing N levels in cocoa.

Our findings align with those of Tian et al. (2008) and Gaudin et al. (2011), who observed enhanced root elongation at low nitrogen levels, suggesting that moderate nitrogen application supports root development. Conversely, Wang et al. (2005) found that high nitrogen availability reduces root biomass, indicating that excess nitrogen may shift the allocation of resources away from root growth. Comfort et al. (1988) further suggested that excessive nitrogen application can impede overall plant growth due to high nitrate levels in the buds, which inhibit starch synthesis and reduce root sugar levels, ultimately affecting root growth (Scheible et al., 1997). Zhang et al. (2017) also noted that excess nitrogen promotes aboveground growth while decreasing root growth, resulting in a higher shoot-to-root ratio.

Niu et al. (2024) observed similar effects in citrus, where excessive nitrogen application increased aboveground biomass and decreased root growth.

These collective findings indicate that high nitrogen application positively impacts leaf and stem biomass production but hinders root biomass production in cocoa. This suggests that high nitrogen application favors the allocation of biomass to leaves and stems at the expense of roots. Consequently, high nitrogen levels in cocoa are likely to increase the percentage of biomass allocated to leaf and stem growth while reducing the biomass allocated to roots. This shift in biomass partitioning highlights the importance of balancing nitrogen application tooptimize overall plant development and maintain a more favorable shoot-to-root ratio.

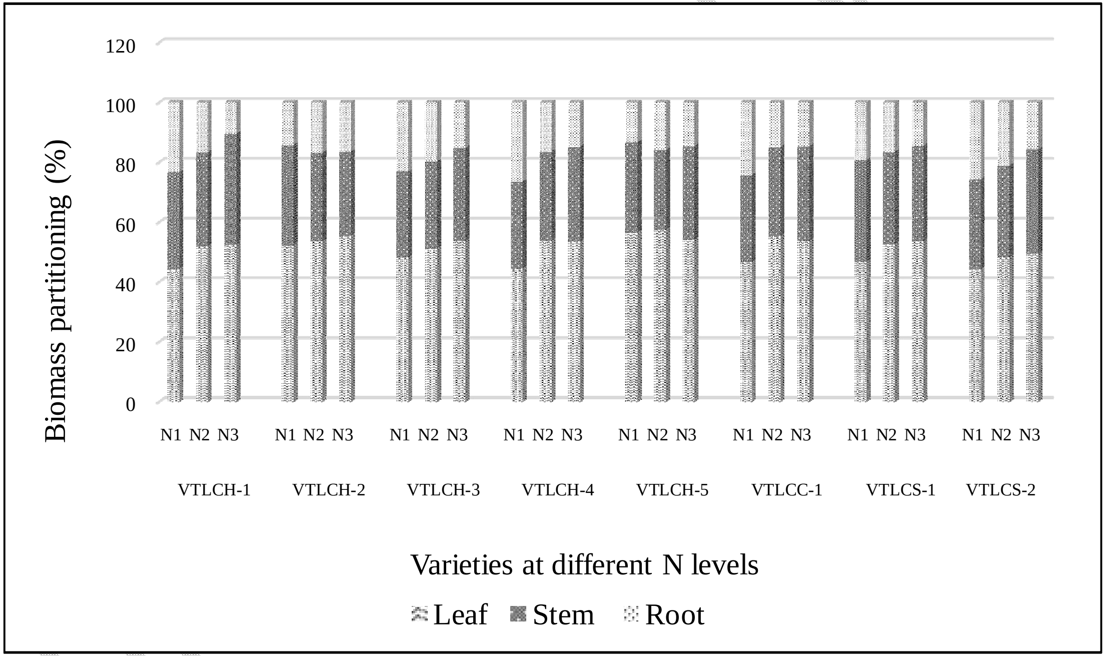

Fig 1. Biomass partitioning to theleaf, stem and root of different cocoa varieties as influenced by varied N levels

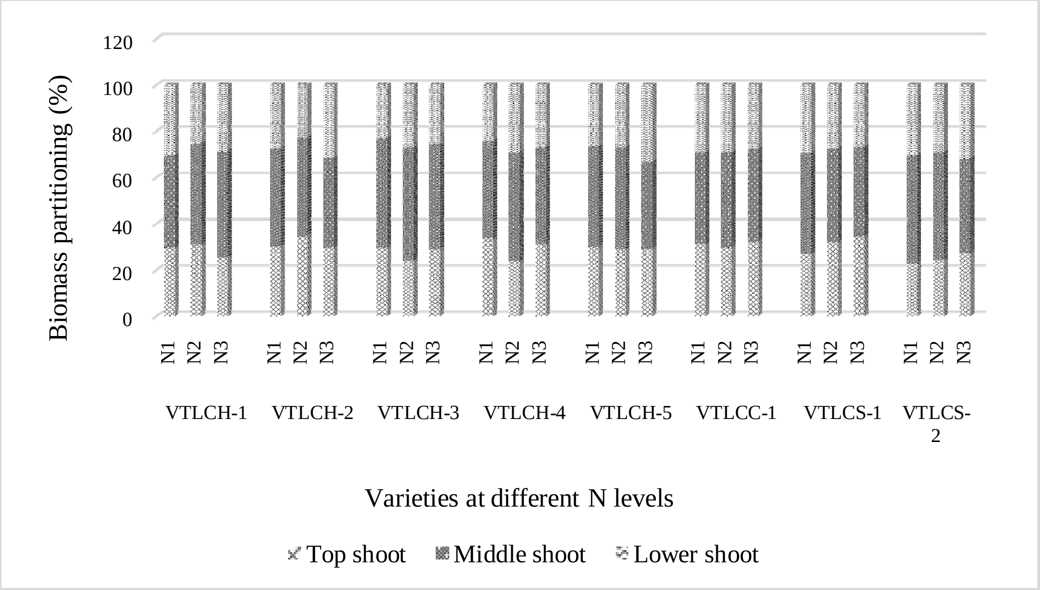

Fig 2. Biomass partitioning to the top, middle and lower shoots of different cocoa varieties as influenced by varied N levels

Table 1. Growth parameters of different cocoa varieties as influenced by varied N levels

Varieties	Plant height (cm)				Number of leaves				Stem diameter (mm)			
	N1	N2	N3	Mean A	N1	N2	N3	Mean A	N1	N2	N3	Mean A
V1	93.00	108.40	125.07	108.82	43.33	54.00	69.33	55.55	10.60	9.67	11.13	10.47
V2	70.57	84.10	76.87	77.18	43.00	44.67	42.00	43.22	9.60	9.43	10.53	9.85
V3	72.00	79.83	91.87	81.23	39.33	44.33	48.67	44.11	8.87	10.87	10.83	10.19
V4	65.43	96.50	102.43	88.12	39.67	47.00	55.00	47.22	8.77	9.87	11.20	9.95
V5	56.33	80.17	97.27	77.92	50.33	42.67	58.00	50.33	9.47	9.60	12.37	10.48
V6	86.67	87.00	98.83	90.83	49.33	44.67	53.67	49.22	10.13	9.80	10.83	10.25
V7	105.00	110.07	85.67	100.25	50.00	63.00	48.67	53.89	10.60	9.70	9.73	10.01
V8	66.90	81.97	96.83	81.90	36.33	37.67	48.67	40.89	10.03	10.70	11.07	10.60
Mean B	76.99	91.01	96.86		43.92	47.25	53.00		9.76	9.96	10.96	
CD at 5%	A=7.30	B=4.47	A+B=12.64		A=4.82	B=2.95	A+B=8.35		A=7.30	B=4.47	A+B=12.64	

Varieties (V): V1-VTLCH-1, V2-VTLCH-2, V3-VTLCH-3, V4-VTLCH-4, V5-VTLCH-5, V6-VTLCC-1, V7-VTLCS-1, V8-VTLCS-2

N levels (N): N_1- N @ 40 ppm, N_2- N @ 80 ppm, N_3-N @ 120 ppm. SEm- Standard Error of means, CD- Critical difference

Table 2. Fresh weight of leaves, stem, root and whole plant of cocoa varieties as influenced by varied N levels

Varieties	Leaves				Stem				Root				Whole Plant			
	N1	N2	N3	Mean A	N1	N2	N3	Mean A	N1	N2	N3	Mean A	N1	N2	N3	Mean A
V1	64.45	67.68	94.64	75.59	53.65	56.74	79.24	63.21	64.45	29.48	18.63	37.52	182.55	153.89	192.52	176.32
V2	59.78	78.28	67.77	68.61	44.74	50.35	45.35	46.81	17.98	26.70	23.93	22.87	122.50	155.33	137.05	138.29
V3	45.89	66.95	72.49	61.78	33.97	48.42	54.79	45.73	25.03	30.36	24.20	26.53	104.90	145.72	151.47	134.03
V4	53.60	80.50	91.24	75.11	37.53	54.48	69.15	53.72	36.66	27.75	29.44	31.28	127.78	162.74	189.83	160.12
V5	57.51	61.92	86.15	68.53	35.41	36.78	69.22	47.14	15.65	23.79	30.54	23.33	108.57	122.49	185.92	138.99
V6	72.30	66.85	77.29	72.15	60.71	46.42	62.65	56.59	58.66	20.91	24.67	34.75	191.67	134.18	164.61	163.49
V7	68.46	84.60	62.61	71.89	57.08	58.49	48.52	54.70	31.20	30.49	22.21	27.97	156.74	173.58	133.34	154.55
V8	42.36	56.07	66.59	55.01	44.71	48.32	61.48	51.50	31.62	30.00	20.53	27.38	118.69	134.39	148.60	133.89
Mean B	58.04	70.36	77.35		45.98	50.00	61.30		35.16	27.43	24.27		139.17	147.79	162.92	
CD at 5%	A=5.34	B=3.27	A+B=9.26		A=4.75	B=2.91	A+B=8.23		A=3.22	B=1.97	A+B=5.58		A=11.22	B=6.87	A+B=19.43	

Varieties (V): V1-VTLCH-1, V2-VTLCH-2, V3-VTLCH-3, V4-VTLCH-4, V5-VTLCH-5, V6-VTLCC-1, V7-VTLCS-1, V8-VTLCS-2

N levels (N): N_1- N @ 40 ppm, N_2- N @ 80 ppm, N_3-N @ 120 ppm. SEm- Standard Error of means, CD- Critical difference

	Shoot:Root	Root:Leaf	Shoot:Fine root

Table 3. Shoot-to-root, Root-to-leaf and Shoot-to-fine root ratios of cocoa varieties as influenced by varied N levels

Varieties	N1	N2	N3	Mean A	N1	N2	N3	Mean A	N1	N2	N3	Mean A
V1	3.35	5.01	8.82	5.73	0.53	0.32	0.20	0.35	37.96	50.09	47.47	45.17
V2	6.12	4.94	5.11	5.39	0.28	0.32	0.30	0.30	61.19	50.64	46.16	52.66
V3	3.34	4.11	5.71	4.39	0.48	0.39	0.28	0.39	42.6	32.81	30.15	35.19
V4	2.83	5.15	5.93	4.63	0.6	0.31	0.28	0.40	61.08	55.14	44.36	53.53
V5	6.54	5.37	5.91	5.94	0.24	0.28	0.27	0.26	55.51	61.00	44.49	53.67
V6	3.12	5.81	5.83	4.92	0.53	0.27	0.28	0.36	31.24	36.48	42.35	36.69
V7	4.20	5.02	5.97	5.06	0.41	0.32	0.27	0.34	58.08	44.60	46.24	49.64
V8	2.93	3.78	5.71	4.14	0.58	0.44	0.32	0.45	42.78	30.63	42.94	38.78
Mean B	4.06	4.90	6.12		0.46	0.33	0.28		48.84	45.17	43.02	4.06
LSD at 5%	A=0.79	B=0.48	A+B=1.37		A=0.06	B=0.03	A+B=0.096		A=4.58	B=2.81	A+B=7.94	

Varieties (V): V1-VTLCH-1, V2-VTLCH-2, V3-VTLCH-3, V4-VTLCH-4, V5-VTLCH-5, V6-VTLCC-1, V7-VTLCS-1, V8-VTLCS-2

N levels (N): N_1- N @ 40 ppm, N_2- N @ 80 ppm, N_3-N @ 120 ppm. SEm- Standard Error of means, CD- Critical difference

CONCLUSION

This study highlights the significant effects of nitrogen (N) levels and varietal differences on growth, biomass production, and biomass partitioning in cocoa varieties. Different cocoa varieties responded distinctly to varying nitrogen levels, affecting overall growth and biomass allocation. VTLCH-1 recorded the highest plant height, number of leaves, and biomass production, particularly at the high N level. Higher nitrogen levels enhanced biomass production in leaves and stems across most varieties, while root biomass was adversely affected, leading to an increased shoot-to-root ratio. This shift in biomass partitioning underscores the necessity of optimizing nitrogen application and selecting suitable cocoa varieties for balanced growth and improved productivity.

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