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RESEARCH ARTICLE

Biomass Partitioning of Cassava (*Manihot esculenta* Crantz) at Various Doses of Nitrogen Fertilization

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Abstract

The distribution of carbohydrates across different plant organs, or carbohydrate partitioning, is a vital indicator of nitrogen use efficiency and resource allocation in plants. This study aimed to evaluate the impact of varying nitrogen fertilization rates on carbohydrate partitioning in cassava (*Manihot esculenta* Crantz). A randomized block design was used with six nitrogen dose treatments (0, 45, 90, 135, 180, 225 kg.ha^{-1}) and four replications. Parameters observed included dry weight and carbohydrate distribution in roots, stems, leaves, root tubers, and petioles over eight months after planting (MAP). Results indicated that nitrogen fertilization significantly influenced cassava plants' dry weight and carbohydrate partitioning, with optimal nitrogen doses varying by plant organ and growth stage. Nitrogen application enhanced carbohydrate allocation to root tubers, particularly from 3 to 8 MAP.

Keywords: carbohydrate partitioning, dry weight, “Mangu” cassava, root tubers

Introduction

Cassava (*Manihot esculenta* Crantz) is a critical carbohydrate source in Indonesia (Wijayanti et al., 2019). Despite its importance, national productivity remains below its potential (Directorate General of Food Crops, 2021). Plant productivity is influenced by genetic and environmental factors, including planting materials, cultivation techniques, and fertilization practices (Wokanubun et al., 2020). Nitrogen fertilization is key in improving cassava growth, root tuber yield, and overall quality. Nitrogen is an essential macronutrient for protein synthesis, nucleic acids, and other cellular components crucial for plant development (Noor et al., 2023). However, inadequate nitrogen availability limits photosynthesis and growth, while excessive nitrogen can reduce yields (Omondi et al., 2019). Therefore, the efficient use of nitrogen through optimal fertilization is vital for cassava productivity.

Carbohydrate partitioning reflects the allocation of photosynthetic products to various plant organs, significantly affecting plant growth and yield (Sonnewald and Fernie, 2018). For cassava, carbohydrate allocation to root tubers is crucial for productivity (El-Sharkawy, 2004). This study investigated how nitrogen fertilization rates influence carbohydrate partitioning in cassava organs, including roots, stems, leaves, root tubers, and petioles.

Materials and Methods

Study Site and Design

The research was conducted at the Sindang Barang Experimental Garden, IPB University, from July 2023 to April 2024. Dry weight measurements were carried out at the Postharvest Laboratory, Department of Agronomy and Horticulture, IPB University. The experiment employed a randomized block design with six nitrogen (N) treatments: N0 (without N fertilizer), N1 = 45 kg.ha^{-1} fertilization (equivalent to 100 kg.ha^{-1} urea), N2 = 90 kg.ha^{-1} fertilization (equivalent to 200 kg.ha^{-1} urea), N3 = 135 kg.ha^{-1} fertilization (equivalent to 300 kg.ha^{-1} urea), N4 = 180 kg.ha^{-1} fertilization (equivalent to 400 kg.ha^{-1} urea), and N5 = 225 kg.ha^{-1} fertilization (equivalent to 500 kg.ha^{-1} urea). Each treatment was repeated four times to obtain 24

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experimental units.

Research Procedures

Land preparation involved plowing, clearing, and dividing the area into four blocks with six plots per block. Each plot measured 7 m x 5.6 m and was separated by 1 m (plots) and 2 m (blocks). Cassava was planted at 1 m x 0.8 m spacing, resulting in 49 plants per plot.

Cassava cuttings ("Mangu" variety) measuring 20 cm were planted vertically to a depth of 10 cm. Fertilization was conducted as follows: nitrogen (Urea, 45% N): applied at planting, 2 MAP, and 4 MAP according to treatments; potassium (KCl): applied at planting and 4 MAP at 100 kg.ha^{-1} per application; phosphorus (SP-36): applied once at planting at 200 kg.ha^{-1}. Fertilizers were applied in furrows 10 cm deep beside plants, which were then covered with soil. Throughout the experiment, regular maintenance, including monthly weeding, was performed.

Observation and Measurements

Destructive sampling was conducted monthly by selecting one plant per treatment, yielding 24 sample plants per observation. Parameters measured included the dry weight of plant organs (roots, stems, leaves, root tubers, and petioles), total dry weight, and carbohydrate partitioning. Plants were uprooted and separated into fibrous roots, stems, leaves, root tubers, and petioles. Fibrous roots develop from the basal stem and function in water and nutrient absorption, while storage roots arise from nodal tissues and serve as starch storage organs (Chaweewan and Taylor, 2015). Plant organ weights were recorded before and after drying. Samples were chopped and oven-dried at 80°C for 48 hours to determine dry weight using an analytical balance (±0.01 g accuracy).

Carbohydrate partition (η) is calculated based on the comparison of the dry weight of plant organs (fibrous roots, stems, leaves, root tubers, and stalks) each month to the total dry weight (DW) in the same month (total DW). $\eta = \frac{DWi}{\text{totaldw}}$

Data were analyzed using analysis of variance (ANOVA) at the 5% level. Regression analysis was performed to determine the pattern of plant response to nitrogen doses. Data processing was performed using R-Studio.

Results and Discussion

Dry Weight of Fibrous Roots, Stems, Leaves, Root tubers, Leaf Petioles and Total Biomass

The fibrous root dry weight increases with rising nitrogen (N) doses, reaching an optimal level typically between 135 kg.ha^{-1} and 180 kg.ha^{-1}. Beyond this range, particularly during the root tuber filling phase, higher N doses (e.g., 225 kg.ha^{-1}) result in a decline in fibrous root dry weight. This suggests that excessive N application may shift resource allocation away from fibrous roots, supporting a quadratic response trend. This response highlights the importance of optimizing nitrogen application to enhance fibrous root development during critical growth phases without compromising resource allocation in later stages.

Stem dry weight showed a significant response to N dose in most growth periods with varying patterns at each growth phase (Table 2). Stem dry weight showed a quadratic response at the early growth phase (1-2 MAP). The response became linear at 3-4 MAP. At 5 MAP, the response returned to quadratic with a significant increase in stem dry weight. The effect of N on stem dry weight began to decline at the root tuber filling phase, with an insignificant response at 7-8 MAP.

Nitrogen (N) fertilization significantly influences the dry weight of cassava leaves, particularly during the early growth and root tuber-filling phases. In the early growth phase (1–2 MAP), a linear increase in leaf dry weight is observed with rising N doses.

N fertilization does not significantly affect leaf dry weight during the maximum vegetative growth phase (3–6 MAP). However, a trend of increased leaf dry weight with higher N doses is still evident, suggesting that N availability may indirectly support leaf biomass accumulation.

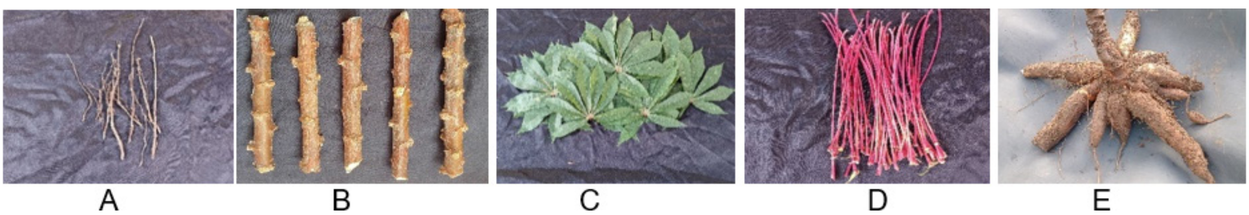

Figure 1. Cassava plant organs (a) fibrous roots, (b) stems, (c) leaves, (d) leaf stalks, and (e) root tubers.

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Table 1. The dry weight of cassava plant fibrous roots at various doses of nitrogen fertilization

N dosages (kg.ha^{-1})	Plant age (MAP)							
	1	2	3	4	5	6	7	8
0	1.12	1.19	2.69	4.19	6.46	3.55	3.32	2.39
45	1.41	1.34	3.54	4.31	8.59	3.95	3.49	4.52
90	1.53	1.50	3.85	4.34	8.70	6.11	4.00	3.63
135	1.47	1.63	7.34	5.80	9.32	8.93	10.11	3.37
180	1.40	1.56	5.27	7.76	10.11	9.35	6.66	2.98
225	1.92	1.54	4.07	4.80	7.03	8.68	5.74	1.41
Response Pattern	-	-	Q**	L**	Q**	L**	Q**	Q**

Note: Q = quadratic; L = linear; ** = 1% significance level; MAP = months after planting.

Table 2. The dry weight of cassava stems from various doses of nitrogen fertilization

N dosages (kg.ha^{-1})	Plant age (MAP)							
	1	2	3	4	5	6	7	8
0	1.49	3.47	23.65	84.15	97.92	278.08	329.20	500.50
45	1.53	4.36	25.66	87.88	146.27	318.68	345.43	511.77
90	1.52	5.57	26.17	99.24	159.39	336.24	347.44	519.59
135	2.41	5.88	27.53	100.22	163.17	363.44	347.89	520.11
180	1.76	6.01	33.04	135.21	183.28	368.39	350.85	536.94
225	1.68	4.28	27.69	115.39	155.84	300.57	324.37	532.86
Response Pattern	Q**	Q**	L**	L**	Q**	Q**	-	-

Note: Q = quadratic; L = linear; ** = 1% significance level; MAP = months after planting.

At the root tuber filling phase (7–8 MAP), the relationship between N fertilization and leaf dry weight reverts to a linear response. This phase-specific effect highlights the critical role of nitrogen in maintaining leaf biomass, particularly during early growth and as the plant transitions to the storage phase, where leaves contribute to photosynthate production for tuber development.

The dry weight of cassava petioles exhibited varying responses to nitrogen (N) fertilization across different growth phases. At the early Growth Phase (1–2 MAP): A quadratic response was observed, with petiole dry weight increasing with nitrogen application up to an optimal dose before declining at higher doses. At the maximum Vegetative Phase (3–4 MAP). At 3 MAP, a linear response was observed, indicating that petiole dry weight consistently increased with higher N doses. At 4 MAP the response shifted to a quadratic pattern, suggesting an optimal N dose beyond which additional N had diminishing or adverse effects.

At the later vegetative phase (5 MAP), nitrogen application did not significantly affect petiole dry weight at this stage. In contrast, at the root tuber filling phase (6–8 MAP), a linear response was observed at 6–7 MAP, indicating a positive relationship between N doses and petiole dry weight. By 8 MAP the effect of N fertilization on petiole dry weight was no longer significant. These findings demonstrate that petiole dry weight responds dynamically to N fertilization, with the response type varying depending on the plant's growth stage. This highlights the need to tailor N applications to the specific growth phases for optimal resource allocation.

Nitrogen (N) dosage affects the dry weight of cassava root tubers with different response patterns depending on the growth phase. Root tuber formation has not occurred in the early phase (1-2 MAP). A quadratic response was observed at 3-4 MAP where cassava plants entered the initiation and early root tuber development phase. A dose of 135 kg.ha^{-1} produced the highest root tuber dry weight. In the root tuber filling phase (5-8 MAP) the response to N fertilization remained significant. The response pattern varied between linear (5-6 MAP) and quadratic at 7-8 MAP. Doses of 135 kg.ha^{-1} and 180 kg.ha^{-1} consistently produced the highest root tuber dry weight.

The total dry weight of cassava plants exhibited a significant response to nitrogen (N) fertilization across all growth phases, with a predominantly quadratic response pattern observed during each stage of plant

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Table 3. The dry weight of cassava leaves at various doses of nitrogen fertilization

N dosages (kg.ha^{-1})	Plant age (MAP)							
	1	2	3	4	5	6	7	8
0	2.57	4.44	30.94	145.55	124.29	121.92	98.41	72.15
45	3.06	4.44	31.74	149.64	126.97	128.20	99.95	76.79
90	3.18	4.76	32.67	150.22	137.11	154.50	104.92	78.74
135	3.72	5.55	33.80	170.62	145.93	150.000	121.41	82.73
180	3.87	5.65	34.46	167.49	155.84	147.40	120.90	85.51
225	3.36	6.46	35.51	150.73	149.31	143.86	116.32	81.04
Response Pattern	L**	L**	-	-	-	-	L**	L**

Note: Q = quadratic; L = linear; ** = 1% significance level; MAP = months after planting.

Table 4. The dry weight of cassava petioles at various doses of nitrogen fertilization

N dosages (kg.ha^{-1})	Plant age (MAP)							
	1	2	3	4	5	6	7	8
0	3.18	2.74	47.46	72.86	71.07	85.89	83.19	42.01
45	3.31	3.60	52.40	75.10	72.69	94.88	83.83	42.96
90	3.49	3.70	53.78	81.93	77.06	95.73	86.85	43.06
135	4.72	4.47	55.55	94.77	77.60	103.69	87.90	43.83
180	3.69	4.07	59.19	73.05	80.17	94.45	90.23	45.36
225	3.29	3.80	61.06	71.06	78.78	90.11	88.31	46.73
Response Pattern	Q**	Q**	L**	Q**	-	L**	L**	-

Note: Q = quadratic; L = linear; ** = 1% significance level; MAP = months after planting.

Table 5. Dry weight of cassava root tubers at various doses of nitrogen fertilization

N dosages (kg.ha^{-1})	Plant age (MAP)							
	1	2	3	4	5	6	7	8
0	0	0	3.72	48.11	403.25	395.08	637.79	642.91
45	0	0	9.38	110.59	418.06	433.55	645.08	661.87
90	0	0	33.45	143.06	427.27	442.17	650.41	776.64
135	0	0	213.91	434.34	471.52	565.54	1005.9	950.45
180	0	0	137.02	240.86	508.38	559.52	948.82	928.33
225	0	0	83.81	217.87	433.06	480.72	781.41	811.36
Response Pattern	-	-	Q**	Q**	L**	L**	Q**	Q**

Note: Q = quadratic; L = linear; ** = 1% significance level; MAP = months after planting.

development. Doses of 135 kg.ha^{-1} and 180 kg.ha^{-1} consistently resulted in the highest total dry weight, indicating that they are the most effective levels of N fertilization for maximizing biomass accumulation.

The quadratic nature of the response suggests that while increasing N application enhances total dry weight up to an optimal point, a higher dose beyond 180 kg.ha^{-1} may lead to a plateau or even a decline in biomass, likely due to nutrient imbalances or diminishing returns on nitrogen use efficiency. These results highlight the importance of applying nitrogen at appropriate levels to optimize cassava growth and resource use while avoiding the adverse effects of over-fertilization.

Carbohydrate Partitioning

Carbohydrate distribution was dominated mainly by leaves and petioles in the early growth phase. The distribution partition for leaves ranged from 0.303 to 0.401, while for petioles, it ranged from 0.232 to 0.383. N fertilization did not show a significant effect on carbohydrate distribution at this phase, which

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Table 6. Total dry weight of cassava plants at various doses of nitrogen fertilization

N dosages (kg.ha^{-1})	Plant age (MAP)							
	1	2	3	4	5	6	7	8
0	8.36	11.84	108.45	354.85	702.98	884.51	1151.90	1259.96
45	9.30	13.74	122.71	427.51	772.57	979.25	1177.77	1297.90
90	9.71	15.53	149.91	478.79	809.52	1034.75	1193.60	1421.67
135	12.31	17.53	338.11	805.74	867.53	1191.60	1573.20	1600.49
180	10.72	17.29	268.97	624.36	937.78	1179.10	1517.45	1599.11
225	10.25	16.07	212.14	559.86	824.02	1023.93	1316.15	1473.39
Response Pattern	Q**	Q**	Q**	Q**	L**	Q**	Q**	Q**

Note: Q = quadratic; L = linear; ** = 1% significance level; MAP = months after planting.

was in accordance with dry weight data, and did not show a significant response to N at 1-2 MAP. The vegetative growth phase was characterized by a shift in carbohydrate distribution from vegetative organs to root tuber organs. The root tuber distribution partition increased from 0 at 2 MAP to 0.034-0.632 at 3 MAP, and continued to increase to 0.527-0.574 at 5 MAP. N fertilization showed a significant effect with a quadratic pattern on root tuber distribution at 3-4 MAP, where the dose of 135 kg.ha^{-1} produced the highest distribution. This correlated with the root tuber dry weight data, which also showed a quadratic response with the highest value at a dose of 135 kg.ha^{-1}. Meanwhile, the distribution to vegetative organs (leaves, stems, petioles) showed a decreasing trend. The leaf distribution partition decreased from around 0.3 at 2 MAP to 0.163-0.181 at 5 MAP. This decrease was offset by increased distribution to root tubers, indicating a shift in carbohydrate allocation priorities. Root tubers are the main storage of carbohydrates with partition partitions ranging from 0.427 to 0.639 at 8 MAP. N fertilization showed a significant effect with a quadratic pattern at 7-8 MAP, where the doses of 135 kg.ha^{-1} and 180 kg.ha^{-1} produced the highest root tuber partition. This correlated with the root tuber dry weight data, which also showed a quadratic response with the highest value at 135 kg.ha^{-1} and 180 kg.ha^{-1}. The distribution to vegetative organs decreased, with the leaf distribution partition decreasing to 0.052-0.059 at 8 MAP. However, the distribution to stems was relatively stable (0.324-0.397 at 8 MAP).

Discussion

Nitrogen (N) fertilization significantly influences cassava growth, dry matter accumulation, and carbohydrate partitioning, with effects varying across growth phases and plant organs. Fibrous roots responded significantly during the maximum vegetative phase (3–5 MAP), showing a quadratic pattern with peak dry weight at doses of 135 kg.ha^{-1} and 180 kg.ha^{-1}. However, excessive N (e.g., 225 kg.ha^{-1}) in the root tuber filling phase (6–8 MAP) caused a decline in fibrous root weight, likely due to physiological stress. Omondi et al., (2019) explained that excess nitrogen causes physiological disorders in plants at higher doses, resulting in decreased yields. Stems exhibited a quadratic response during the early growth phase (1–2 MAP), with optimal dry weight at the dose of 180 kg. ha^{-1}, reflecting the role of N in early structural development. Ekanayake et al., (2018) explained that nitrogen application significantly increased early vegetative growth in cassava plants, especially in the first few months. During the maximum vegetative phase (3–5 MAP), N fertilization continued to enhance stem growth, while in the root tuber filling phase (7–8 MAP), dry weight increases were minimal due to nutrient remobilization from stems to root tubers. Munyahali et al. (2023) reported that nitrogen plays an important role in increasing the rate of photosynthesis that supports the vegetative growth of plants, including stems. However, as explained by El-Sharkawy (2004), during the tuber filling phase, the stem serves as a temporary storage site and a transport pathway for photosynthates to other organs. As a result, in this phase, nutrient remobilization occurs, including the transfer of nutrients from the stem to the root tubers.

Leaves and petioles showed notable responses to N, especially in the early growth (1–4 MAP) and root tuber filling (6–8 MAP) phases. Leaf dry weight exhibited a linear response during early growth, while petiole dry weight followed a quadratic pattern, indicating optimal growth at moderate N doses. Although N had no significant effect on leaf weight during the maximum vegetative phase, a trend of increased weight at higher doses was observed. In the root tuber filling phase, N fertilization maintained the canopy structure, supporting photosynthetic activity. Maintaining a healthy leaf canopy during the root tuber filling phase is essential to ensure optimal yields, as leaves directly affect the photosynthetic capacity of plants and the

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Table 7. Distribution of carbohydrates at various doses of nitrogen fertilizer

Plant Parts	N dosages (kg.ha^{-1})	Plant age (MAP)							
		1	2	3	4	5	6	7	8
Fibrous root	0	0.133	0.101	0.025	0.012	0.009	0.004	0.003	0.002
	45	0.151	0.098	0.029	0.010	0.011	0.004	0.003	0.003
	90	0.157	0.097	0.026	0.009	0.011	0.006	0.003	0.003
	135	0.119	0.093	0.022	0.007	0.011	0.007	0.006	0.002
	180	0.131	0.090	0.019	0.013	0.011	0.008	0.004	0.002
	225	0.187	0.097	0.019	0.009	0.008	0.008	0.004	0.001
Response Pattern		-	-	L**	-	-	L**	Q**	Q**
Stem	0	0.179	0.293	0.218	0.238	0.139	0.313	0.284	0.397
	45	0.165	0.314	0.209	0.208	0.189	0.327	0.293	0.394
	90	0.156	0.359	0.175	0.207	0.196	0.325	0.291	0.365
	135	0.194	0.335	0.081	0.128	0.188	0.306	0.221	0.324
	180	0.165	0.348	0.123	0.218	0.195	0.313	0.231	0.336
	225	0.163	0.265	0.130	0.206	0.187	0.294	0.246	0.362
Response Pattern		-	Q**	L*	L**	Q**	-	L*	L*
Leaf	0	0.308	0.375	0.286	0.410	0.177	0.141	0.086	0.057
	45	0.329	0.324	0.258	0.349	0.163	0.130	0.085	0.059
	90	0.328	0.305	0.218	0.313	0.171	0.149	0.088	0.055
	135	0.303	0.317	0.100	0.212	0.168	0.126	0.077	0.052
	180	0.359	0.326	0.129	0.267	0.166	0.125	0.080	0.054
	225	0.328	0.401	0.168	0.268	0.181	0.140	0.088	0.055
Response Pattern		-	Q**	L**	L**	-	-	-	-
root tuber	0	0	0	0.034	0.134	0.574	0.443	0.555	0.510
	45	0	0	0.076	0.256	0.542	0.442	0.548	0.510
	90	0	0	0.223	0.300	0.527	0.427	0.545	0.547
	135	0	0	0.632	0.533	0.544	0.474	0.639	0.594
	180	0	0	0.509	0.385	0.542	0.474	0.626	0.581
	225	0	0	0.394	0.390	0.528	0.469	0.594	0.551
Response Pattern		-	-	Q**	Q**	-	-	Q*	Q*
Petiol	0	0.381	0.232	0.438	0.134	0.101	0.099	0.073	0.034
	45	0.355	0.264	0.428	0.256	0.094	0.098	0.071	0.033
	90	0.359	0.239	0.359	0.300	0.095	0.093	0.073	0.030
	135	0.383	0.255	0.164	0.533	0.090	0.087	0.056	0.027
	180	0.345	0.236	0.220	0.385	0.086	0.080	0.059	0.028
	225	0.321	0.237	0.289	0.390	0.096	0.088	0.067	0.032
Response Pattern		Q**	-	L*	L**	-	L*	L**	-

Notes: Q = quadratic; L = linear; * = 5% significance level; ** = 1% significance level; MAP = months after planting.

translocation of carbohydrates to storage organs (Kirkby et al., 2023). Root tuber formation began at 3 MAP, where a quadratic response to N peaked at dose of 135 kg.ha^{-1}, emphasizing the importance of sufficient N for tuber initiation. Sufficient N availability is very important in the early stages of root tuber formation. N supports leaf formation and vegetative development of plants which can ultimately increase photosynthesis and carbohydrate storage in potato root tubers (Ospina et al., 2014). During the root tuber filling phase, N3–N4 consistently produced the highest tuber dry weight, whereas

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excessive N (e.g., 225 kg.ha^{-1}) disrupted growth, potentially due to imbalances between vegetative and reproductive development. The optimization of nitrogen fertilization significantly enhances cassava root tuber yield by promoting vegetative growth and improving photosynthetic efficiency, leading to greater carbohydrate accumulation in the root tubers (Kirkby et al., 2023). Furthermore, El-Sharkawy (2004) explains that the balance between vegetative growth and root tuber development is crucial for achieving optimal cassava yield.

Total dry weight of cassava followed a quadratic response to N fertilization, with optimal growth at dose of 135 kg.ha^{-1}, while higher doses led to reduced efficiency or potential toxicity. Malcolm et al., (2023) explained that too high a dose of N can result in toxicity and antagonism in the absorption of other nutrients, which can ultimately reduce the efficiency of nitrogen use and biomass production. Carbohydrate partitioning patterns shifted over time. During the early growth phase, vegetative organs, particularly leaves and petioles, dominated allocation, supporting photosynthesis and biomass accumulation. As plants transitioned to the vegetative growth phase (3–5 MAP), partitioning shifted toward root tubers, increasing from 0.034–0.632 at 3 MAP to 0.527–0.574 at 5 MAP, with dose of 135 kg.ha^{-1} facilitating this transition. During the root tuber filling phase, tubers became the primary carbohydrate sink, reaching 0.427–0.639 at 8 MAP, while allocation to leaves and petioles decreased. Adiele et al. (2020) reported that biomass allocation to root tubers increased over time while in the crown decreased. Stems remained stable, reflecting their role as temporary storage organs and nutrient translocation pathways. De Souza et al. (2017) reported that cassava stems are temporary organs that store carbohydrates and other nutrients, which are then mobilized to the root tubers at the end of the maximum vegetative phase until the root tuber filling phase. Excessive N disrupted these dynamics, reducing overall efficiency and yields.

Optimal N fertilization at 135 kg.ha^{-1} or 180 kg.ha^{-1} enhances photosynthesis, dry matter accumulation, and carbohydrate partitioning, balancing vegetative and reproductive growth. Proper timing and moderate doses of N ensure efficient resource allocation, prevent physiological stress, and maximize cassava yields, highlighting the importance of sustainable nutrient management in cassava production. Kirkby et al. (2023) emphasize that proper nitrogen management can optimize biomass distribution and enhance crop yield.

Conclusion

Nitrogen fertilization significantly affects cassava dry weight and carbohydrate distribution, with the optimal dose varying according to plant age and organs. Generally, nitrogen application enhances total biomass and promotes carbohydrate allocation to root tubers, mainly between 3–8 MAP. Optimal nitrogen doses in this study range from 135 kg.ha^{-1} to 180 kg.ha^{-1}, which can maximize the efficiency of carbohydrate partitioning to root tubers while maintaining sufficient vegetative growth to support overall plant productivity. Our study demonstrated the importance of managing effective nitrogen fertilization to optimize cassava yield by aligning fertilization practices with the dynamic carbohydrate partitioning throughout the growth cycle.

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