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Planting position and application of different doses of nitrogen at different times on cassava

Posição de plantio e da aplicação de diferentes doses de nitrogênio em diferentes épocas em mandioca

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ABSTRACT

In this study, we evaluated the impact of two planting positions of cassava cuttings, cv. 'Vassourinha', combined with different times and doses of nitrogen application, on productivity and other agronomic traits. In the experiment, the treatment was completely randomized using a 2 × 3 × 4 factorial scheme with two positions of the cuttings [horizontal (PH) and vertical (PV)], three instances of N application (45, 90, and 135 days after planting), and four doses of N (0, 80, 160, and 240 kg ha^{-1}), with six repetitions. We recorded and evaluated the plant height, number of shoots, stem diameter, biomass of the aerial part, number of commercial roots, the total production, and the collection index. The addition of 240 kg ha^{-1} N and PH increased plant height and stem diameter but did not affect the number of commercial roots, total production, or the collection index. The treatment involving the addition of nitrogen fertilizer 135 days after planting with 240 kg ha^{-1} N and planting in the PV provided the highest amount of shoot biomass without influencing crop productivity.

Index terms: *Manihot esculenta*; production technology; planting methods; N application.

RESUMO

Neste estudo, avaliamos o impacto de duas posições de plantio de mudas de mandioca, cv. 'Vassourinha', combinada com diferentes épocas e doses de aplicação de nitrogênio, sobre a produtividade e outras características agronômicas. No experimento, o tratamento foi inteiramente casualizado em esquema fatorial 2 × 3 × 4 com duas posições das estacas [horizontal (PH) e vertical (PV)], três momentos de aplicação de N (45, 90 e 135 dias após plantio) e quatro doses de N (0, 80, 160 e 240 kg ha^{-1}), com seis repetições. Registramos e avaliamos a altura da planta, o número de brotações, o diâmetro do caule, a biomassa da parte aérea, o número de raízes comerciais, a produção total e a índice de coleta. A adição de 240 kg ha^{-1} de N e PH aumentou a altura das plantas e o diâmetro do caule, mas não afetou o número de raízes comerciais, a produção total ou o índice de coleta. O tratamento com adição de fertilizante nitrogenado 135 dias após o plantio com 240 kg ha^{-1} de N e plantio no PV proporcionou a maior quantidade de biomassa da parte aérea sem influenciar a produtividade da cultura.

Palavras-chave: *Manihot esculenta*; tecnologia de produção; métodos de plantio; aplicação de N.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is an excellent source of fiber and starch and is an important food source worldwide (Suppakul et al., 2013; De Oliveira et al., 2021). Furthermore, it is regarded as a subsistence food item in several tropical regions of Africa, Latin America, and Asia (Food and Agriculture Organization Corporate Statistical Database - FAOSTAT, 2019). The largest producers of this crop in the world are Nigeria, Congo, Ghana, Thailand, Indonesia, and Brazil, with over 290 million tons of production in 2017 (FAOSTAT, 2019). In Brazil, cassava is produced in almost all regions, especially in the states of Bahia, Mato Grosso do Sul, and Pará, with an annual production of approximately 19 million tons and a planted area of 1.4 million hectares (Instituto Brasileiro de Geografia e Estatística - IBGE, 2020).

In Brazil, although the crop can adapt to various agroecosystems, cassava has a high genotype x environment interaction (Otsubo et al., 2009; Barros et al., 2020) and is mainly planted on small farms, many of which are used for family farming and distribution to small local industries (Aguiar et al., 2021). Crop management determines the productive potential and is neglected in many cases because it is considered a crop that responds to low inputs (Vieira; Fialho; Silva, 2007; Aguiar et al., 2021) combined with the incidence of pests and diseases.

The improvement of nitrogen (N) management is particularly important in cassava growing regions, where N inputs are high and extreme weather events, like changing rainfall patterns and long dry/wet cycles, occur (Chirinda et al., 2021). Nitrogen is an essential nutrient and extremely important for plant growth (Taiz et al., 2017). It improves crop production and the uptake of other nutrients (Zuffo et al., 2021; Ullah et al., 2022). Crop productivity is associated with the management of fertilization; 146 kg of potassium (K), 123 kg of nitrogen (N), and 46 kg of calcium were extracted to produce approximately 25 tons of cassava roots per hectare (Mattos; Bezerra, 2003). Soares et al. (2016) and Burbano-Figueroa, Pérez-Pazos and Moreno-Moran (2022) reported that an adequate supply of NPK macronutrients could increase the yield of the crop. Mattos and Bezerra (2003) reported that nitrogen management influences the hydrocyanic acid content (Cardoso Júnior et al., 2005a) and productive performance (Dos Santos et al., 2014; Oliveira et al., 2017).

Cassava responds well to the application of nitrogen fertilizers, which can be provided through chemical sources (urea or ammonium sulfate) or organic fertilizers (manure, cake, compost, green manure, etc.). These fertilizers should be applied in the pit or furrow (Mattos; Bezerra, 2003). Urea should be applied around the plant 30 to 60 days after sprouting in moist soil (Mattos; Bezerra, 2003); however, this is rarely done by producers, thus limiting productivity (Cardoso Júnior et al., 2005b; Dos Santos et al., 2014).

Cassava productivity is also influenced by the care provided at the time of planting. Proper care includes maintaining the size and positioning of the stake at planting (Hartati et al., 2021), as well as, the health of the plant material used, the diameter of the plant, the conservation period after collection, and variations in the responses of the crop (Alves, 2006). Most producers plant cassava horizontally on flat land with little or no slope (Gabriel Filho et al., 2003).

From a physiological perspective, positioning can stimulate the hormonal balance (auxins and gibberellins) that occurs in seedlings by triggering the germination of the buds. Early germination can quickly block the rows in the field, thus preventing the growth of weeds and the evaporation of water (Alves, 2006). Planting branches vertically can improve the agronomic performance of cassava, especially in sandy soils (Cerqueira et al., 2016; Hartati et al., 2021). Vertical planting can facilitate deeper growth of the roots. However, no study has evaluated cassava regarding the various ways in which the plants are planted and the effects of different doses of nitrogen on the development of the culture. In this study, we evaluated the effect of two planting positions of cassava cuttings, cv. ‘Vassourinha’, combined with different times and doses of nitrogen application on the yield and other agronomic traits.

MATERIAL AND METHODS

The experiment was conducted at the experimental study area of the Federal University of Mato Grosso do Sul (Universidade Federal de Mato Grosso do Sul-UFMS), Chapadão do Sul campus (18°4618″ S, 52°3725″ W; altitude: 810 m). According to the Koppen classification, the region has a tropical rainy (Aw) climate, with dry winters and rainy summers. The precipitation, average temperature, and annual relative humidity are 1, 261 mm, 23.97 °C, and 64.23%, respectively (Alvares et al., 2014). For the duration of the experiment, the mean air temperature was 23.5 °C (±2.1 °C), the mean air relative humidity was 64.5% (±8%), and the total rainfall was 1,826 mm (Figure 1); these data were obtained from the Instituto Nacional de Meteorologia [Weather District of the National Meteorology Institute) (INMET)].

The soil used for the experiment was classified as red Latosol (Santos et al., 2018) with a clayey texture. Before the experiment, the soil was sampled using an auger at the 0.00–0.20 and 0.20–0.40 m layers at five points in each plot. The average values of the chemical properties of the soil are shown in Table 1.

Based on the chemical analysis of the soil (Table 1), the acidity was reduced by the application of limestone (CaO: 29%; MgO: 20%; PRNT: 90.1%; PN: 90.5%) to increase the saturation per soil base in the experimental area to 60%. Liming was performed two months before the experiment by applying 513 kg ha^{-1} limestone superficially and incorporating a grid.

For maintaining a constant level of moisture, irrigation was performed using a drip irrigation system with Streamline Netafim Hoses, and emitters of 0.30 m were applied once every 24 h in the first two weeks and then every 48 h. This facilitated a favorable environment for the development of cassava.

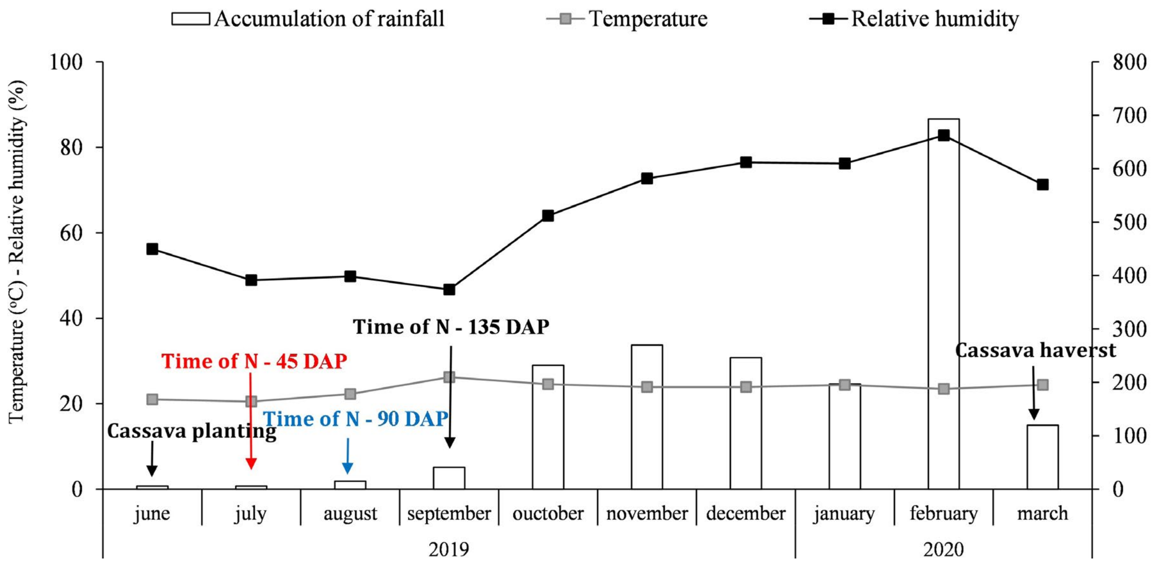

Figure 1: The rainfall, atmospheric temperature, and relative humidity during the experiment in Chapadão do Sul, MS, 2019/2020. The time of N application [45, 90, and 135 days after planting (DAP)], and cassava harvest are shown.

Table 1: The main chemical properties of the soil used in the experiment under the environmental conditions of Chapadão do Sul.

Depth (m)	pH $CaCl_2$	OM ($g\ dm^{-3}$)	PMehlich^{-1} ($mg\ dm^{-3}$)	H+Al	Al^{3+}	Ca^{2+}	Mg^{2+}	K^{+}	CEC	S
				cmolc dm^{-3}						%
0.00 – 0.20	5.2	27.5	6.0	3.8	0.12	3.20	1.10	0.25	8.4	54.5
0.20 – 0.40	4.8	30.1	5.5	4.8	0.07	2.70	0.80	0.20	8.5	43.5

OM: Organic matter. CEC: cation exchange capacity at pH 7.0. V: Base saturation.

The seedlings of the 'Vassourinha' Cassava cultivar (0.02 m in diameter) were prepared and cut to a length of 0.20 m to obtain uniform stems for planting.

A randomized block experimental design was used, following a 2 × 3 × 4 factorial scheme. The factors included the positioning of the plant [horizontal (PH) and vertical (PV)], the time of N application [45, 90, and 135 days after planting (DAP)], and the dose of nitrogen [0, 80, 160, and 240 kg ha^{-1} urea (45% N)], with six replicates per treatment. The experimental units consisted of four lines that were 3 m long, with a spacing of 0.90 m between rows and 0.60 m between plants. Cassava was planted on 7th June (2019). Plants grown in the inner two lines were considered for data collection. Additionally, 0.5 m from the edges of each line was also rejected, leaving a useful area per plot of 1.8 m^2.

The treatments associated with the planting position were performed by placing the 0.20 m long (approx.) seedlings in the pits using a hoe. The seedlings were left in the vertical position with approximately half of them buried in the soil. The seedlings planted horizontally were completely buried in the field, and the same spacing was maintained for both treatments (Figure 2). Manual weeding was performed to control weeds when necessary.

Four plants per plot were selected randomly at 286 DAP, and the following traits were measured: plant height (PHe, m), the number of shoots (NS, unit), stem diameter (SD, mm), and the biomass of the aerial part (BAP, kg $plant^{-1}$). The number of commercial roots (NCR, unit), the total production (TP, t ha^{-1}), and the collection index (CI, unit) were also measured. The biomass of the aerial part was measured using a digital scale by separating the aerial part (including the stem and leaves of each plant) from the roots. The number of commercial roots was performed by counting the total number of roots that were more than 4 cm in diameter and not considering non-commercial roots in the analysis. The total production was measured on a digital scale using all commercial and non-commercial roots.

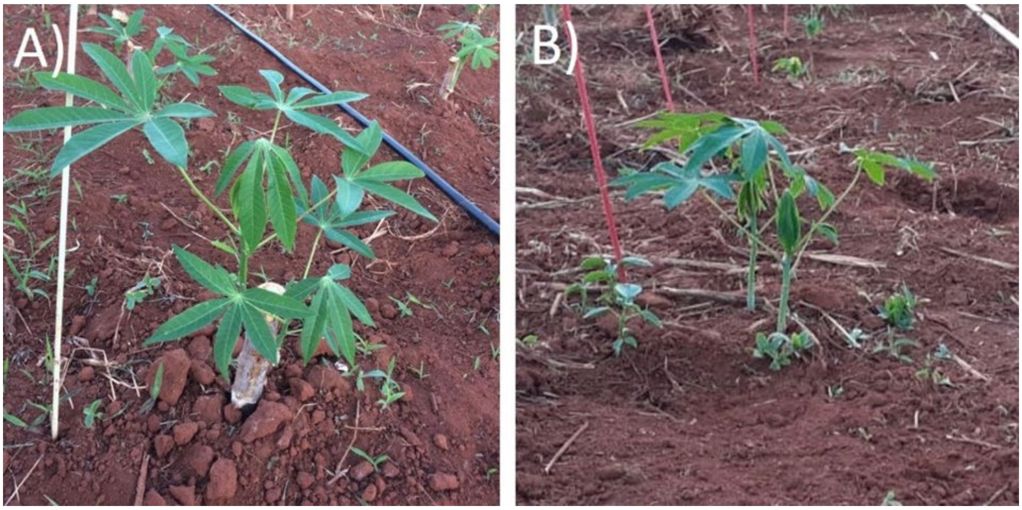

Figure 2: A comparison of the two planting strategies based on the planting position, (A) vertical and (B) horizontal, and the development of cassava shoots from the time of planting; Chapadão do Sul, MS.

The assumptions of normality and the homogeneity of variances were verified for the data (Kolmogorov, 1933). A double-rank ANOVA based on a fixed-effects linear model (Fisher, 1937) was performed. The comparison between the means was performed by conducting Tukey's test, and the differences were considered to be statistically significant at $P \leq 0.05$. Regression analyses were performed for the biomass of the aerial part as a dependent variable with positioning and the time of application of nitrogen as independent variables. The graphs were plotted using the SigmaPlot software version 11.0. The ANOVA and comparison between means were performed using the Rbio software version 140 for Windows (Bhering, 2017).

RESULTS AND DISCUSSION

The climatic conditions during the growing season were suitable, with an average temperature of 23.5 °C, relative humidity of 64.5%, and accumulated precipitation greater than 1,800 mm. For cassava, the period 1 to 5 months after planting corresponds to the initiation and tuberization stages of the roots. A water deficit of two months within this period can reduce the root yield from 32% to 60% (Alves, 2006). The total rainfall in the first three months (June to August) was only 62 mm, and the water required for the development of the plants was provided by the irrigation system that was installed in the study area. After these three months, the precipitation became regular. The highest total rainfall of 693 mm occurred in February. There was no water stress, and the crops developed well (Figure 1).

The time of N application (TNA) did not affect the measured characteristics significantly under the conditions of our study. The different doses of N applied significantly affected plant height, stem diameter, and biomass of the aerial part. The position of the seedling significantly affected plant height, the number of shoots, stem diameter, and biomass of the aerial part (Table 2).

The interaction terms between different variables (TNA x ND, TNA x P, and ND x P) did not affect the evaluated traits significantly (Table 2). The triple interaction (TNA x ND x P) significantly affected the biomass of the aerial part only (Table 2). The coefficients of variation obtained were satisfactory for the field experiments and showed that the data obtained were precise.

The mean performances of the morphological and yield traits were calculated and are presented in Table 3. The time of N application did not affect any of the estimated traits significantly. However, treatment with nitrogen 135 days after planting increased plant height and improved total root production. The application of N in cassava has not been investigated extensively, although its use is recommended (Mattos; Bezerra, 2003). The management of nitrogen, based on the element to be extracted, is recommended for its application 30 to 60 days after the sprouting of the stakes (Mattos; Bezerra, 2003); thus, nitrogen can influence the productive performance of cassava (Dos Santos et al., 2014; Oliveira et al., 2017). Our results indicated that nitrogen treatment beyond 135 DAP, as described by Mattos and Bezerra (2003), can promote a better response under the tested conditions (Table 3).

Table 2: The analysis of variance and the p-value of some agronomic and yield traits in cassava cv. 'Vassourinha' planted in two positions and treated with a nitrogen fertilizer at different doses and application times; Chapadão de Sul, MS.

Source of variation	DF	p-value[1]						
		PHe (m)	NS (unit)	SD (mm)	BAP (kg plant^{-1})	NCR (unit)	TP (t ha^{-1})	CI (unit)
Time of N application (TNA)	2	0.31	0.71	0.99	0.16	0.13	0.61	0.62
Doses of N (ND)	3	0.04	0.24	0.04	0.03	0.22	0.17	0.86
Positioning (P)	1	0.04	0.08	0.004	0.05	0.60	0.36	0.11
TNA x ND	6	0.10	0.14	0.59	0.46	0.14	0.97	0.93
TNA x P	2	0.43	0.61	0.34	0.98	0.41	0.80	0.94
ND x P	3	0.25	0.22	0.47	0.27	0.73	0.82	0.97
TNA x ND x P	6	0.36	0.47	0.14	0.03	0.73	0.36	0.99
coefficient of variation (%)		9.25	26.42	10.01	8.89	4.95	5.31	19.55

[1]Plant height (PHe), number of shoots (NS), stem diameter (SD), biomass of the aerial part (BAP), o number of commercial roots (NCR), total production (TP) and collection index (CI).

Table 3: The mean performance of some agronomic and yield traits in cassava cv. 'Vassourinha' planted in two positions under the effect of different doses of nitrogen fertilizer with three application times; Chapadão de Sul, MS.

Treatments	PHe[1] (m)	NS (unit)	SD (mm)	NCR (unit)	TP (t ha^{-1})	CI (unit)
Time of N application (DAP)						
45	2.07	1.69	24.46	7.41	28.42	0.38
90	2.02	1.80	24.42	6.41	31.33	0.33
135	2.40	1.80	24.50	6.42	36.39	0.33
P <0.05	NS	NS	NS	NS	NS	NS
N doses (kg ha^{-1})						
0	1.92 b	1.95	22.81 b	6.11	24.26	0.33
80	2.04 b	1.73	23.40 b	6.83	29.03	0.38
160	2.13 b	1.63	25.77 b	6.39	34.91	0.32
240	2.74 a	1.78	25.93 a	7.47	43.38	0.36
P <0.05		NS		NS	NS	NS
Positioning						
Horizontal	2.60 a	1.91	23.72 a	6.76	38.46	0.29
Vertical	2.00 b	1.70	23.43 b	6.63	29.92	0.37
P <0.05		NS		NS	NS	NS

[1]Plant height (PHe), number of shoots (NS), stem diameter (SD), number of commercial roots (NCR), total production (TP), and collection index (CI). DAP, days after planting. Different letters in the column represent significant differences by the Tukey test at *P*<0.05 probability.

Nitrogen is responsible for several physiological and biochemical processes in plants (Zuffo et al., 2021) and is a structural constituent of chlorophyll, proteins, enzymes, and nucleic acids (Nunes-Nesi; Fernie; Stitt, 2010; Taiz et al., 2017). Thus, plants with adequate levels of N have a high chlorophyll content, which can increase the photosynthetic rate and photoassimilate production and, consequently, improve the productive performance of cassava. The results showed that increasing the dose of nitrogen increased the plant height and the stem diameter of cassava; specifically, the highest dose of nitrogen (240 kg ha^{-1}) was associated with the highest values of plant height (2.74 m) and stem diameter (25.93 mm) ($P < 0.05$) (Table 3). The effects of nitrogen applied were similar to those found by Cardoso Junior et al. (2005b), who found a linear effect of the nitrogen dose on the height of cassava plants when using doses of up to 400 kg ha^{-1}. The tall plants also had a greater number of commercial roots and higher yield; however, there were significant differences associated with the remaining doses (Table 3).

Nitrogen promotes a greater production of vegetative material (aerial part), and this effect was reported in the cassava crop by this study and other studies (Cardoso Junior et al., 2005b; Dos Santos et al., 2014); specifically, we found that 240 kg ha^{-1} nitrogen can promote the highest PHe of 2.74 m (Table 3). Similarly, Gazola et al. (2018) showed that the levels of ferulic, caffeic, and p-coumaric acids were affected by the time and amount of nitrogen application in cassava.

Stem diameter (SD) is an important characteristic when branches are used as a propagation method for developing a new plantation (Ceballos et al., 2010) and the accumulation of reserves; thus, stem diameter enhances the resistance of the plants to climatic conditions in the field. The lignin content in the stem determines this process. Applying the highest dose of N (240 kg ha^{-1}) showed the best response regarding the SD, with an average value of 25.93 mm and significant differences ($P < 0.05$) relative to the other doses used (Table 3). For younger plants, the part of the stem selected for cutting must be highly lignified; however, highly lignified parts have low food reserves, reduced viability, delayed and slow germination, and/or low vigor (Ceballos et al., 2010).

The position in which the seedlings were planted had the same effect as the application of N, i.e., it only stimulated the plant height and stem diameter; the horizontal positioning increased the plant height and stem diameter by 30% and 1%, respectively (Table 3). The other variables were not significantly affected by the treatments; however, the highest values for the number of shoots, the number of commercial roots, and total production were found for horizontal positioning, with increments of 12%, 2%, and 29%, respectively (Table 3). Cerqueira et al. (2016) reported that the position of the seedling during planting had significant effects ($P < 0.01$) on the BAP and SD, which was confirmed in this study.

From a physiological perspective, positioning can stimulate the hormonal balance (auxins and gibberellins) in seedlings by triggering the germination of the buds. This causes the rows in the field to be quickly occupied, thus preventing the growth of weeds and evaporation of water (Alves, 2006). Positioning was also studied by Viana et al. (2000), who found that horizontally planted roots had the highest yield (20.292 kg ha^{-1}). Cerqueira et al. (2016) found contrasting results. They evaluated the positioning at planting and found the best results in the vertical position for the BAP and SD, which were different for the horizontal positioning. Contrasting results were obtained for positioning while planting cassava (PH and PV) in clayey (Viana et al., 2000) and sandy loam soils (Cerqueira et al., 2016). Vertical positioning (PV) is most effective in sandy soils where maximum root development is achieved. However, in clayey soils, the arrangement of the roots when planting vertically wastes the energy of the plants and makes harvesting difficult, as found in this study.

The interaction between the three factors significantly affected the biomass of the aerial part (see Figure 3 and Table 4). The effects of the different doses of N at 45, 90, and 135 DAP are presented in Figures 3A, 3B, and 3C, respectively. Irrespective of the factors evaluated, quadratic equations with moderate and high regression coefficients were obtained for the biomass of the aerial part (Figure 3). Treatment with 240 kg ha^{-1} nitrogen fertilizer at 45 and 90 DAP produced the highest amount of biomass of the aerial part, greatest stem diameter, and most number of commercial roots in combination with PH. At 135 DAP, the biomass of the aerial part further increased after treatment with 240 kg ha^{-1} N; however, in combination with the PV, it increased by 7.25 kg $plant^{-1}$. This probably occurred because the production of green matter increased due to large amounts of available nitrogen. These results were similar to those obtained by Gabriel Filho et al. (2003), who found that high doses of nitrogen (up to 400 kg ha^{-1} N) lead to the production of a large number of shoots.

In the absence of the application of N (Table 4), the positioning did not differ regardless of the time of application. This showed that in the absence of N, the vegetative development of the plants was not affected. The biomass of the aerial part strongly influences the cultivation of cassava because the branches are used as the propagation material for the installation of new production fields or for the production of rations of excellent protein quality, used for feeding different animals (Mattos, 2006).

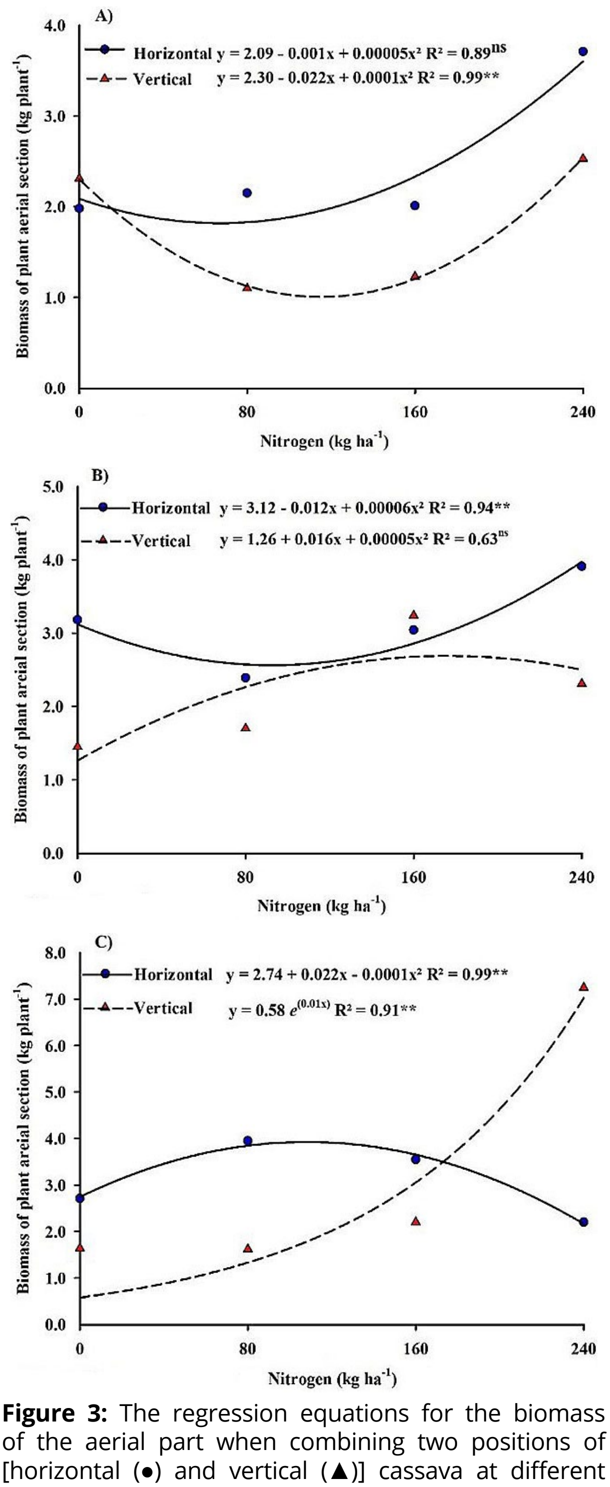

Figure 3: The regression equations for the biomass of the aerial part when combining two positions of [horizontal (●) and vertical (▲)] cassava at different application times [45 (A), 90 (B), and 135 (C) days after planting (DAP)] as a function of different doses of nitrogen (0, 80, 160, and 240 kg ha^{-1}) under the conditions of Chapadão do Sul, MS, 2020.

Table 4: The mean performance of the biomass of the aerial part (kg planta^{-1}) in cassava cv. 'Vassourinha' for two planting positions under the effect of different doses of nitrogen fertilizer and three application times, Chapadao do Sul, MS, 2020.

Nitrogen (kg ha^{-1})	Time of application (days after planting)	Positioning	
		Horizontal	Vertical
0	45	1.98a	2.30a
	90	3.16a	1.45a
	135	2.71a	1.65a
80	45	2.15b	1.10a
	90	2.39b	1.70a
	135	3.95a	1.62a
160	45	2.01b	1.23b
	90	3.04b	3.24a
	135	3.54a	2.20b
240	45	3.71a	2.53b
	90	3.91a	2.31b
	135	2.20a	7.25a

At 80 kg ha^{-1} N (Table 4), the PH differed ($P < 0.05$), showing that the highest BAP values were observed at 135 DAP. At 160 kg ha^{-1} N, both positions differed ($P < 0.05$), and at 135 DAP and 90 DAP, the PH and PV, respectively, showed the highest BAP values (Table 4). At 240 kg ha^{-1} N (Table 4), only the PV differed at 135 DAP. The results showed that PH stimulated BAP when 80 and 160 kg ha^{-1} N were applied in the last application period (135 DAP), thus ensuring the maximum development of the BAP of the crop. The PV was better only at higher doses of N (240 kg ha^{-1}) and equal to the PH in the last application period (135 DAP).

The management of N needs to be improved in cassava-growing regions, for example, in Cerrado, where extreme weather events occur, including changing rainfall patterns and long dry/wet cycles (Chirinda et al., 2021). Crop productivity is associated with fertilization management. In a study, 123 kg N was extracted to obtain an approximate production of 25 t ha^{-1} the cassava (Mattos; Bezerra, 2003). Nitrogen management influences shoot growth, which contributes to the increase in photosynthetic tissue and favors the production of carbohydrates for the roots and productive performance (Gabriel Filho et al., 2003), as found in this study.

Cassava can adapt to different agroecosystems and shows a high genotype x environment interaction (Otsubo et al., 2009). It responds to the high heterogeneity of the places where it is planted, ranging from small properties to large areas that supply the roots to small local and national industries (Aguiar et al., 2021). The crop responds to nutritional management that determines the productive potential, which in many cases is neglected, as it is considered to be a crop that responds to low inputs (Vieira; Fialho; Silva, 2007; Aguiar et al., 2021).

The timing of nitrogen application in cassava has not been investigated as extensively as that in other crops, such as *Triticum aestivum* L. (Yano; Takahashi; Watanabe, 2005), *Phaseolus vulgaris* L. (Arf et al., 2011), and *Oryza sativa* L. (Hernandes et al., 2010), where many studies have addressed this topic. Mattos and Bezerra (2003) reported that cassava should be treated with urea 30 to 60 days after sprouting when the soil is moist. In this study, different doses of N were applied at 45, 90, and 135 DAP, although no effects of N were found on the variables measured, except for BAP. For BAP, the interaction between the three factors for treatment with 240 kg ha^{-1} of N applied at 135 DAP and PV showed the best results. Nitrogen treatment was more suitable at 135 DAP, i.e., almost halfway through the crop cycle under the conditions tested, considering the rapid adsorption of N and its effect on photosynthesis and the production of photoassimilates for the plant. This treatment showed the highest production of roots and total productivity. Although the values were higher, they did not differ significantly compared to those in the other application periods (45 and 90 DAP).

Nitrogen is a macroelement that affects the cassava plant, as indicated by the results of this study. The best time to apply N in the cassava crop was not known, which reinforces the importance of these results. Applying 240 kg ha^{-1} N at 135 DAP caused greater development of the area, plant height, and stem diameter; however, it did not stimulate PT to the extent that it would show differences between the various doses of N administered. The rate of N fertilization in highly fertile soils needs to be regulated to minimize N loss because of the high levels and prolonged periods of soil moisture. In cassava-growing regions, N management needs to be improved, especially where extreme weather events are changing rainfall patterns.

CONCLUSIONS

Treatment with 240 kg ha^{-1} N and PH increased plant height and stem diameter but did not affect the number of commercial roots, the total production, or the collection index. The interaction of the time of N application, the dose of N, and the positioning of the plants showed significant effects only on the biomass of the aerial part; the biomass was the highest at 240 kg ha^{-1} N applied at 135 DAP in the vertical position. However, the interaction of these three factors did not affect crop productivity.

AUTHOR CONTRIBUTIONS

Conceptual Idea: Aguilera, J.G.; Krewer, B.I., Methodology design: Aguilera, J.G.; Zufoo, A.M.; Ratke, R.F., Data collection: Aguilera, J.G.; Krewer, B.I.; Ribeiro, N.J.; Data analysis and interpretation: Aguilera, J.G.; Zufoo, A.M.; Ratke, R.F., Elsayed, A.Y. and Writing and editing: Aguilera, J.G.; Zufoo, A.M.; Ratke, R.F.; Elsayed, A.Y.

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