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Effect of Harvest Time and Nitrogen Doses on Cassava Root Yield and Quality

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ABSTRACT: Nitrogen is considered the most limiting nutrient for cassava, and N availability can influence the crop cycle, including earlier harvest. The aim of this study was to study the effect of harvest time on the production components of cassava, "Aciolina" cultivar, at different rates of N fertiliser. The experiment was carried out in an area newly incorporated into the productive system in a savannah ecosystem in the northern Amazon. A randomised block experimental design was used in a split plot arrangement with four replications. The N rates (0, 30, 60, 150, and 330 kg ha^{-1}) were allocated to the main plots, and the harvest times (90, 120, 150, 180, 240, 300, and 360 days after emergence of the stalks - DAE) were allocated to the subplots. Plant height, shoot fresh matter yield, number of roots per plant, average root diameter, and root fresh matter yield display an increasing linear response up to 360 DAE in cassava cv. "Aciolina". For all harvest times, the N rates promote an increase in root fresh matter yield. At 300 and 360 DAE, the root fresh matter and starch yield and the harvest index show a quadratic response as a function of the N level. The greatest efficiency of N topdressing on the production of root fresh matter occurs at 300 DAE, promoting an earlier harvest. At that time, the dose of maximum technical efficiency, 226 kg ha^{-1} N, results in a yield of 62 Mg ha^{-1} of root fresh matter, 13 Mg ha^{-1} of starch, and a harvest index of 81 %.

Keywords: *Manihot esculenta*, cassava, crop cycle, nitrogen fertiliser, Amazonian savannah.

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INTRODUCTION

Cassava (*Manihot esculenta* Crantz), a Euphorbiaceae native to the Amazon region bordering Venezuela (Cagnon et al., 2002), is one of the main energy foods required by more than 700 million people in at least 105 countries. The most widely exploited product of the crop is starch, both for its nutritional importance and its use in the textile, pharmaceutical, food, and paper industries (Nunes et al., 2009).

In Brazil, cassava is cultivated on 1.5 million hectares, with a production of 22.8 million tonnes and an average yield of 15.2 Mg ha^{-1} (IBGE, 2016). In the world ranking, Brazil occupies the 21th position for cassava yield, with India in first place with a yield of 36.5 Mg ha^{-1} (Faostat, 2015). In general, this low yield is due to the use of few inputs in managing the crop, and its cultivation in marginal areas. Because of this and the high demand for cassava products, the use of nutrients through fertilisation is inevitable in the near future (Adjei-Nsiah e Sakyi-Dawson, 2012).

In the Amazon, it has been found that after each crop cycle without the use of external nutrients (inputs), there is a reduction of 0.72 Mg ha^{-1} in cassava roots (Jakovac et al., 2016). In Thailand, new cultivars are planted in 100 % of the cultivated area and 70 to 80 % of farmers use chemical fertilisers, achieving average yields in excess of 20 Mg ha^{-1} (Vilpoux, 2008).

Among the soil nutrients, N is cited as the most taken up by cassava (Ayoola e Makinde, 2007; Adjei-Nsiah, 2010; Santos et al., 2014). The availability of N is affected by the low levels of organic matter present in the soil reserved for its cultivation. Reichert et al. (2015) found no effect on the production of cassava from the rate of decomposition and release of nutrients by fragmentation of residue from the litter in the Amazonian environment. Such results are possibly due to the low levels of nutrients present in these residues and to the high losses through leaching (Stewart et al., 2006). For cassava, especially, the process of losses is aggravated by the wide spacing between plants, up to 2.0 m between rows and up to 1.0 m in the row, as well as the long period of cultivation, since the crop remains for up to 21 months in the field (Sagrilo et al., 2002; Ayoola and Makinde, 2007; Silva et al., 2013).

Despite the fact that the natural supply of N in tropical soils is limited, N fertiliser is not used by most farmers in cultivating cassava. The growth and development of cassava therefore takes place under conditions of N deficiency, which results in limits on its production potential (Cruz et al., 2006). Nitrogen fertilisation promotes an increase in plant height, shoot production, root yield, number of roots per plant, and the starch and protein content of the leaves (Cardoso Júnior et al., 2005; Asare et al., 2009; Kaweewong et al., 2013). However, an excess of available N can reduce tuberous root production due to promotion of excessive shoot development (Tsay et al., 1989). Plant response to N is also influenced by the cultivar cycle, given that short-cycle cultivars respond to higher rates of N and are more efficient in its use (Byju and Anand, 2009).

Tropical soils, especially those of the Brazilian Amazonian savannah, invariably display low fertility and an organic matter content that does not exceed 1 % (Benedetti et al., 2011). It is necessary to use soil correction and fertilisation practices to include it in the production process. In the cassava crop, the study of N is justified due to its low labile reserves and high uptake (180 kg ha^{-1}). We tested the hypothesis that greater N availability increases root yield, improves quality (higher starch content), and allows earlier harvest time. The aim was to evaluate production and quality components in cassava root to determine harvest time and the nitrogen application rate in topdressing in a first-year area of savannah environment in the northern Amazon, in Boa Vista, Roraima, Brazil.

MATERIALS AND METHODS

The experiment was carried out from October 2010 to October 2011, in the experimental area of the Centre for Agrarian Sciences at the Federal University of Roraima - CCA/UFRR in the city of Boa Vista, state of Roraima, Brazil (2° 52′ 20.7″ N, 60° 42′ 44.2″ W, at an average altitude of 90 m). According to the Köppen classification system, the climate is type Aw, with two well-defined seasons, one rainy (April to August) and the other dry (September-March) (Araújo et al., 2001). Climatic data obtained during the experimental period relating to rainfall, average temperature and relative humidity are shown in figure 1 (Inmet, 2012).

The soil in the experimental area is classified as a *Latossolo Amarelo distrocoeso* (Oxisol), with a sandy-clay-loam texture and gently rolling topography. The soil is deep and well drained, with signs of laminar erosion, an absence of stoniness and rockiness, and dominant vegetation of park savannah (Benedetti et al., 2011).

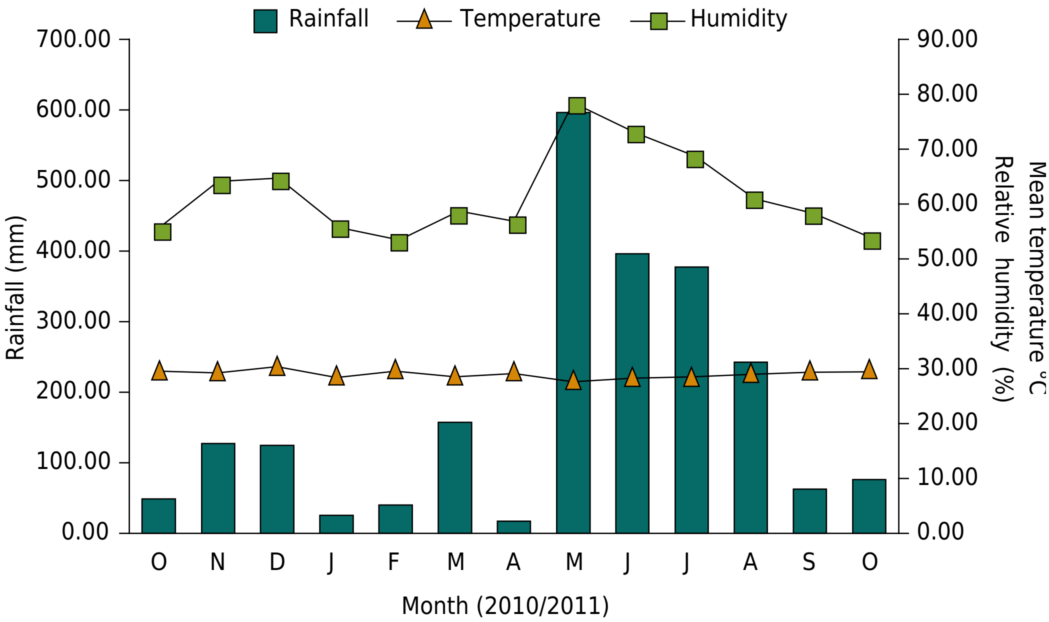

Figure 1. Mean monthly values for rainfall, mean air temperature, and relative humidity from October 2010 to October 2011. Boa Vista, Roraima, Brazil.

Table 1. Chemical and physical properties of the soil in the experimental area for the 0.00-0.20 and 0.20-0.40 m depth layers prior to setting up the experiment

Property	0.00-0.20 m	0.20-0.40 m
pH(H_2O)	5.16	5.06
P (mg dm^{-3})	0.9	0.5
K (mg dm^{-3})	67	70
Ca^{2+} ($cmol_c$ dm^{-3})	0.89	0.24
Mg^{2+} ($cmol_c$ dm^{-3})	0.13	0.03
Al^{3+} ($cmol_c$ dm^{-3})	0.21	0.51
H+Al ($cmol_c$ dm^{-3})	1.0	1.2
SB ($cmol_c$ dm^{-3})	1.19	0.45
T ($cmol_c$ dm^{-3})	2.19	1.65
V (%)	54.3	27.3
m (%)	15.0	53.1
OM (g kg^{-1})	6.7	4.0
Coarse sand (g kg^{-1})	410	360
Fine sand (g kg^{-1})	300	290
Silt (g kg^{-1})	70	90
Clay (g kg^{-1})	220	260
Textural class	Sandy-clay-loam	Sandy-clay-loam

pH(H_2O): pH in water, 1:2.5 v/v; P and K: extractor Mehlich-1; Ca, Mg and Al: extractor 1 mol L^{-1} KCl; H+Al: extractor 0.5 mol L^{-1} calcium acetate; SB: sum of bases; T: cation exchange capacity; V: base saturation; m: aluminium saturation; OM: soil organic matter (Walkley-Black method); coarse sand, fine sand, silt, clay: pipette method (Claessen, 1997).

Physical and chemical analysis of soil samples from the study area at 0.00-0.20 and 0.20-0.40 m layers soil are in table 1.

The cassava cultivar Aciolina was used, an ethnovariety first described by Nunes and Lameira (1983) in competition trials in a savannah environment in the state of Roraima. This cultivar belongs to the Cassava Germplasm collection at the Department of Plant Science of CCA/UFRR, and is the cultivar most planted in the state of Roraima as it has the best set of desirable characteristics (low flour yield, and easy cooking of the root) for both consumption *in natura* (sweet cassava) and for industry, explaining its intense cultivation and marketing (Alves et al., 2008; Oliveira et al., 2011).

The experiment was set up following a randomised block design in a split plot arrangement, with four replications. The N was topdressed (source urea) in random distribution over the subplot at the determined rates, and the harvest time in days after emergence (DAE) was randomly distributed over the subplot. The application doses of N topdressing (0, 30, 60, 150, and 330 kg ha^{-1}) were broadcast over each area, divided into two applications, at 30 and 60 DAE (CFSEMG, 1999). The application doses were set considering the high levels of N, 180 kg ha^{-1}, removed by the crop (CTCRI, 1983). The harvest times were 90, 120, 150, 180, 210, 240, 300, and 360 DAE, the interval required for root tuberisation (Alves, 2006).

An experimental plot consisted of nine single rows of cassava containing 11 plants each, with a spacing of 0.8 × 0.8 m between plants, for a total of 99 plants per plot and an area of 63.36 m^2. Sampling of the plants over time (subplots) was through taking samples from three plants in one of the seven central rows, not including the border of 0.8 m at each end of the plot.

The area where the crop was planted was under natural vegetation, with no history of cultivation or management, consisting of an herbaceous layer, with species of the families Poaceae and Cyperaceae predominating - environmental characteristics of the Roraima savannah, also known as Lavrado (Barbosa et al., 2007). A no-till system was adopted in the area, with no soil turnover and maintenance of the straw on the ground. Thirty days prior to planting, liming and corrective fertilisation of the soil were carried out, based on the general recommendation of Embrapa Roraima (Schwengber et al., 2005) and soil analysis - 1,000 kg ha^{-1} of dolomitic limestone (PRNT 100 %), 90 kg ha^{-1} P_2O_5 (triple superphosphate), 60 kg ha^{-1} of K_2O (potassium chloride), and 30 kg ha^{-1} N (ammonium sulphate) by broadcasting, without incorporation.

Ten days before planting, the natural vegetation was desiccated using a glyphosate-based herbicide. Cassava cuttings measuring 0.20 m were placed horizontally at an approximate depth of 0.10 m into holes, which were dug manually using a hoe.

When planting, the holes received a supplement per hole of 32 g dolomitic limestone, 1.28 g P_2O_5 (single superphosphate), 0.64 g K_2O (potassium chloride), and 3.2 g FTE BR 12 powder (1.8 % B, 0.8 % Cu, 3.0 % Fe, 2.0 % Mn, 0.10 % Mo, and 9.0 % Zn). This supplemental fertilisation was to increase the availability of Ca, Mg, P, and K in the root zone, considering the low levels of these elements in the soil.

From October 2010 to April 2011, supplemental irrigation by a conventional sprinkler system was employed. Moisture was monitored by tensiometers installed at a depth of 0.20 m at six points in the experimental area. Irrigation was activated when the soil water potential was around -20 kPa, and the area was irrigated at flow rate of 3,000 L h^{-1} (Fabrimar ECO A320) three times a week, following technical recommendations for the crop.

During the experiment, weed control was by manual hoeing, considering the critical period of competitive interference, 30 to 75 DAE (Albuquerque et al., 2008).

The samples were collected manually, removing three complete plants from the effective area per split plot. The following variables were evaluated: plant height, measured from the insertion of the stem with the root; shoot fresh matter yield; number of roots per plant;

average root diameter - obtained by calliper rule, measured at the central part of the root and classified into fine, medium and coarse, according to criteria established by Fukuda and Guevara (1998); average root length; root fresh matter yield, estimated by obtaining the fresh weight of the roots for 1 ha; harvest index - the ratio of root fresh weight to total plant fresh weight (HI%) = [(root fresh weight)/(root fresh weight + shoot fresh weight)] × 100; and starch yield (STY) - estimated from the following formula: STY = [(root yield × starch content)]/100. The starch content (SC) was determined by the hydrostatic balance method (Grosmann and Freitas, 1950) using the formula SC = DMC (dry matter content). To determine the dry matter content, the formula DMC = 15.75 × R was used, where R (specific weight) is the weight of roots immersed in water. The SC was determined after 240 DAE, when there was a minimum of 3 kg of root fresh matter per split plot.

The results were subjected to analysis of variance and regression analysis using the SISVAR software, which was selected as the best model to express the influence of N and harvest time on the characteristics under evaluation. The model selected for each variable was chosen based on the significance of the parameter coefficients and the values for R^2 (Alvarez V and Alvarez, 2006). The t-test was used to test the regression coefficients.

RESULTS AND DISCUSSION

The interaction between the application doses of N and harvest times was significant for the variables studied, except for the root length variable. The linear model best described the variables as a function of harvest time, except for root length and harvest index, which were best described by the quadratic function (Figure 2). Starch content was studied only as a function of the N rate at 300 DAE, and was described by the quadratic model.

Plant height was positively affected by harvest time and N rate. Greater availability of N promoted a daily average increase in height, observed by means of the angular coefficient of the functions, ranging from 0.30 to 0.43 cm (Figure 2a). The shoot fresh matter yield (SFM) was affected by the harvest time, except at the doses of 0 and 30 kg ha^{-1} N topdressing (Figure 2b). However, the SFM at the dose of 30 kg ha^{-1} N (8.0 Mg ha^{-1}) was greater than the treatment with no N topdressing (4.9 Mg ha^{-1}), demonstrating the importance of N in the initial phase of plant growth on formation of the canopy. The doses of 150 and 330 kg ha^{-1} N stood out in relation to the others, providing daily average increases of 45.8 and 48.1 kg ha^{-1} SFM, respectively. These increases are related to the increase in photosynthetic tissue, which favours the production of carbohydrates for the roots (Viana et al., 2001).

The plants not fertilised with N topdressing rate of 0 kg ha^{-1} N displayed a reduction in their production potential for all harvest times (Figures 2a, 2b, 2c, 2d, 2e, and 2f). These plants, at 360 DAE, had, on average, 8.0 roots per plant, with an average diameter of 4.77 cm and a yield of 20.34 Mg ha^{-1} of root fresh matter. In contrast, at the highest rate of N topdressing (330 kg ha^{-1}), the plants had, on average, 8.6 roots per plant, with an average diameter of 5.70 cm and a yield of 55.55 Mg ha^{-1} of root fresh matter (Figures 2c, 2d and 2e). Due to the greater availability of N, increases of 7.50, 21.28, and 173.10 % were found in the number of roots, average root diameter, and root fresh matter yield, respectively.

The difference in the number of roots per plant seen between the highest and lowest rate of N decreased with the period of cultivation (Figure 2c), showing that this characteristic was not a determining factor in yield at 360 DAE. The optimal value recommended for the crop is nine roots per plant (Cock, 1979), close to the values obtained, which ranged from 8.0 to 8.6 roots per plant for the lowest and highest rate of N, respectively.

For average root diameter, a greater range was found between the highest and lowest rates of N, from 4.77 to 5.70 cm. Due to the characteristics of the cultivar for consumption *in natura*, these roots were classified as thin, at rates of 0 and 30 kg ha^{-1}, and intermediate, at rates of 60, 150, and 330 kg ha^{-1} N, according to criteria established by Fukuda and

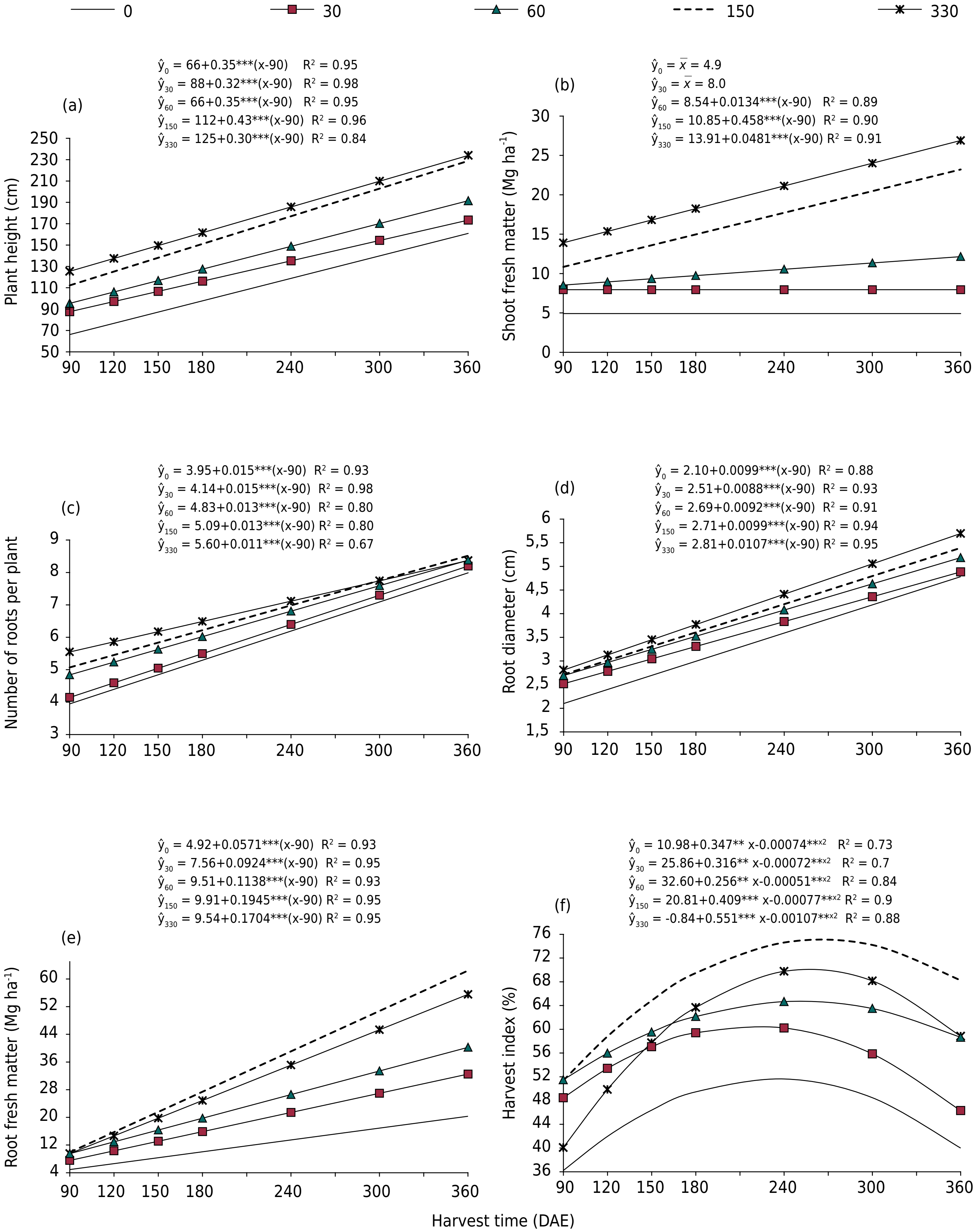

Figure 2. Production components of cassava, cv. Aciolina, for harvest time - (a) plant height; (b) shoot fresh matter yield; (c) number of roots per plant; (d) root diameter; (e) root fresh matter yield; and (f) harvest index for different levels of nitrogen topdressing. ** and ***: significant at 1 and 0.1 % probability by the F-test.

Guevara (1998). This increased thickening of the roots may explain the high average increases seen in root fresh matter yield, especially at 150 and 330 kg ha^{-1} N, which were 194.50 and 170.40 kg ha^{-1}, respectively. Usually, the number and length of roots do not constitute production components limiting to yield in cassava, as they can be offset by a growth in diameter. Figueiredo et al. (2014) found a close positive correlation between root fresh matter and root diameter, whereas the number of roots explained only 60 % in the IAC 576-70 cultivar.

Root length as a function of harvest time was described by the quadratic function $\hat{y} = 43.22 + 0.158^{**} x - 0.00024^{*} x^2$ ($R^2 = 0.98$). Root growth continued up to 329 DAE, close to the period established by Conceição (1981), from 6 to 10 months. The average length of 69.2 cm was greater than that reported in the literature (Alves et al., 2008; Albuquerque et al., 2009; Albuquerque et al., 2012; Figueiredo et al., 2014). This can be attributed to the characteristics of the cultivar, which, due to its smaller diameter, makes up for lower tuberisation by increasing length.

The accumulation of root fresh matter increased over time, irrespective of the rate of N topdressing. The average daily increase ranged from 57.10 to 194.50 kg ha^{-1} for the treatments with no topdressing and with 150 kg ha^{-1} N topdressing, respectively (Figure 2e). These results demonstrate that the length of time the crop remains in the field tends to increase yield, regardless of the levels of N topdressing. At 360 DAE, the yield without N topdressing was 20.34 Mg ha^{-1}, higher than the national average of 15.2 Mg ha^{-1} (IBGE, 2016), showing that a management practice of fertilisation with 30 kg ha^{-1} N, which took place during preparation of the area, favoured improved performance in the plants that did not receive topdressing. However, it can be seen in figure 2e that the adoption of N topdressing increased the gains in root fresh matter yield to 62.43 Mg ha^{-1} at 360 DAE, greater than the average achieved in India and Thailand, which make use of mineral fertiliser, improved cultivars (Vilpoux, 2008), and plant production potential, which is estimated at 60 Mg ha^{-1} (Cock, 1990).

The harvest index (HI) displayed quadratic behaviour, irrespective of the doses of N topdressing (Figure 2f). The maximum HI achieved was 75 % at 266 DAE in plants that received 150 kg ha^{-1} N topdressing. Conversely, the plants grown without N topdressing had a maximum HI of 52 % at 235 DAE. The harvest index is considered suitable at values greater than 60 % (Conceição, 1981); therefore, plants that received N topdressing had an HI value above the minimum considered suitable between 219 and 266 DAE. It can be seen that the highest value for HI (75 %) occurred for harvests from 240 to 300 DAE, showing that harvest can take place before 360 DAE for this cultivar when it is grown with a topdressing of N fertiliser. Viana et al. (2001) found similar quadratic behaviour for HI, concluding that the variation in HI was more influenced by production of root fresh matter than by the fresh matter of the shoots. Silva et al. (2002) also reported that greater values for HI are related to increased root production. Sangrilo et al. (2008) did not fit any model to HI values as a function of plant age, noting that the lowest values for the harvest index were observed during periods of more intense vegetative growth, while the greatest proportion of carbohydrates were allocated to the tuberous roots during periods of low vegetative growth.

The results showed the possibility of obtaining high values for HI at less than 360 DAE (Figure 2f). An early harvest determines roots that are more tender, with a lower fibre content, giving the product improved sensory quality for consumption *in natura*.

Root fresh matter yield, starch content, and harvest index as a function of the N application rate were evaluated at 300 and 360 DAE (Table 2). The quadratic model best fit the data. The first derivative of the quadratic function determined the dose of maximum technical efficiency (DMTE) for each variable in both periods.

Table 2. Equation for root fresh matter yield, starch yield, and harvest index (HI) for doses of nitrogen topdressing applied to a crop of cassava cv. "Aciolina", at 300 and 360 DAE

	Root	Starch	HI
	Mg ha^{-1}		%
		300 DAE	
Equation	$\hat{y}$ = 16.7+0.398* x - 0.000882*** x^2	$\hat{y}$ = 3.6 + 0.087* x - 0.000197*** x^2	$\hat{y}$ = 43.8 + 0.336* x - 0.00076*** x^2
R^2	0.99	0.98	0.98
DMTE (kg ha^{-1} N)(1)	226	221	221
Variable for DMTE	62	13	81
Increment(2)	45.3	9.4	37.2
Efficiency (%)(3)	271	261	85
		360 DAE	
Equation	$\hat{y}$ = 19.5 + 0.378* x - 0.000859*** x^2	$\hat{y}$ = 4.5 + 0.083* x - 0.000184*** x^2	$\hat{y}$ = 43.8 + 0.269* x - 0.00066*** x^2
R^2	0.98	0.95	0.95
DMTE (kg ha^{-1} N)(1)	220	226	204
Variable for DMTE	61	14	71
Increment(2)	41.5	9.5	27.2
Efficiency (%)(3)	213	211	62

(1) DMTE: dose of maximum technical efficiency for N topdressing. (2) Increment: variable for DMTE - variable for a dose of 0 kg ha^{-1} of N topdressing. (3) Efficiency (%) = {[(variable for DMTE × 100)/(variable for a dose of 0 kg ha^{-1} of N topdressing)] - 100}. * and ***: significant at 5 and 0.1 % probability by the F-test, respectively.

The values for DMTE that determined the greatest yields of fresh root matter and starch and the greatest HI were 226, 221, and 221 kg ha^{-1} N respectively, for the harvest at 300 DAE. With the harvest at 360 DAE for the same variables, the DMTE was 220, 226, and 204 kg ha^{-1} N, respectively (Table 2). Root fresh matter yield was 62 and 61 Mg ha^{-1}, starch yield was 13 and 14 Mg ha^{-1}, and the HI was 81 and 71 % at 300 and 360 DAE, respectively. The DMTE increased the yields of root fresh matter and starch by 271 and 261 % at 300 DAE, which then decreased to 213 and 211 % at 360 DAE. The HI displayed an efficiency of 85 and 62 % for the harvests at 300 and 360 DAE, respectively. These results show that high production potential of cassava is highly dependent on the availability of N. In a study by Byju and Ananad (2009), the dose that determined maximum technical efficiency was 100 kg ha^{-1}, although a dose of 200 kg ha^{-1} has been used in short-cycle crops in India.

The efficiency of root fresh matter yield, starch yield, and HI was higher at 300 DAE than at 360 DAE (Table 2), and the DMTE was between 150 and 330 kg ha^{-1}. In figure 2e, it can be seen that in using 150 kg ha^{-1} N, 360 DAE are needed to obtain 62 Mg ha^{-1} root fresh matter. This same yield can be achieved at 300 DAE using 226 kg ha^{-1} N. The DMTE for N topdressing allows an earlier harvest but increases production costs, which should be evaluated by the producer as to viability. Considering that the "Aciolina" cultivar is the most suitable for consumption *in natura*, a longer time in the field may reduce its sensory qualities, making it more suitable for harvest at 300 DAE.

The sweet cassava crop should be harvested earlier, as it will have fewer fibrous roots, with better culinary and sensory qualities (Aguiar et al., 2011). Mendonça et al. (2003) demonstrated from their results that a crop remaining in the field for a longer period might cause diseases, such as root rot, which then affects the final yield.

The quadratic model best fit the data for root production as a function of N rate at 300 and 360 DAE. This shows that high rates of N topdressing, in excess of the DMTE, cause a reduction in production components (Table 2). Kaweewong et al. (2013), studying the response curve of the cassava plant to N rates in four soils in Thailand, found that doses greater than 312 kg ha^{-1} N reduced yield. An excess of N may favour plant growth and reduce tuberisation (Tsay et al., 1989). Asare et al. (2009) found that the use of

60 kg ha^{-1} N increased root yield (to 39.2 Mg ha^{-1}) compared to the absence of N fertiliser, in the savannah in Ghana.

Advantage of N fertilisation can also be verified through the fertilisation efficiency index, which compares yield with and without the use of fertiliser (DMTE), exhibiting values in this study of 271 and 213 % at 300 and 360 DAE, respectively (Table 2). Kaweewong et al. (2013), in a study of cassava production in different soils in Thailand, found efficiency from 53.8 to 211 % for doses ranging from 188 to 250 kg ha^{-1} N, achieving a fresh root yield from 30 to 64 Mg ha^{-1}. These results confirm that with fertilisation it is possible for this crop to reach its production potential.

Greater availability of N, in addition to increasing root production, also stimulates rapid growth in shoots of the cassava plant, thus reducing exposure of the soil to the action of such erosive factors as heavy rainfall, as well as reducing extreme variations in temperature and soil moisture, favouring both biological activity and ecological relationships (Mercante et al., 2008).

Adopting the practice of applying N in topdressing on two occasions (at 30 and 60 DAE) may have improved the efficiency of the N fertiliser, possibly by reducing losses, which, according to Byju et al. (2008), can range from 50 to 60 %. In a study on the efficiency of N fertilisation in cassava cultivars of long and short duration, Byju and Anand (2009) concluded that the rate and period of application of the N are important factors in N uptake efficiency.

The set of techniques proposed here should be considered with a view to raising the production levels of cassava in the Amazonian savannah, especially in a first-year area. Noteworthy are the use of an improved cultivar, supplemental irrigation, and proper management of soil fertility, particularly N fertilisation, given its low availability, vulnerability to loss (leaching, volatilisation, and erosion), and high crop demand.

Supplemental irrigation, although it increases production costs, is necessary during root formation and tuberisation. A study on the critical limits of soil moisture for the cassava crop showed that water stress significantly reduces the total leaf area of cassava plants due to lower diffusion of CO_2 by the stomata, which remain closed for a longer period (Pinheiro et al., 2014). In contrast, greater soil water availability favours plant development and increases the area for interception of solar radiation for photosynthesis and production of photoassimilates that are used for starch accumulation in the roots (Tironi et al., 2015). Souza et al. (2010) obtained a starch yield of 5,180 kg ha^{-1} at nine months after planting, and they were able to triple that yield when harvest took place at 18 months after planting in a crop irrigated throughout its cycle.

Soil management should be a no-till or minimum tillage system rather than conventional tillage, to reduce soil loss caused by soil turnover, and soil exposure due to slow plant growth (Otsube et al., 2008). Fasinmirin and Reichert (2011) noted that cassava develops successfully under a no-till system and achieves an optimum level of growth and production, and no-till conserves the physical properties of the soil.

CONCLUSIONS

Plant height, shoot dry matter yield, number of roots per plant, average root diameter, and root fresh matter yield in the cassava cv. “Aciolina” display linear growth as a function of harvest time up to 360 days after emergence.

An increase in the rate of nitrogen topdressing promotes increases in plant height, shoot and root dry matter yield, the number of roots per plant, and root diameter for all harvest times.

The dose of maximum technical efficiency, 226 kg ha^{-1} of nitrogen in topdressing, results in a yield of 62 Mg ha^{-1} for root fresh matter and 13 Mg ha^{-1} for starch, and a harvest index of 81 %.

The greatest efficiency of nitrogen topdressing in the production of fresh root matter occurs at 300 DAE, promoting earlier harvest in an open area of the Amazon savannah.

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