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Corn Hybrids Response to Nitrogen Rates at Multiple Locations in Brazilian Amazon

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Abstract

Among the nutritional requirements of corn crop, nitrogen (N) is the element required in greater quantity and, directly responsible for increase or decrease in grain production. The aims of study were to evaluate the effects of applied N rates in topdressing in development and production of corn in Brazilian Amazon. The experiments were installed on 20 January 2014 (Capitão Poço city) and 24 January 2014 (Paragominas city). The experimental design was a randomized block design in a 5 × 2 factorial scheme, consisting of five N rates of topdressing applications (0; 40; 80; 120; and 160 kg ha^{-1} of N) and two corn double hybrids (AL-Avaré; and AL-Bandeirante), with four replicates. The evaluations of vegetative development components (plant height, height of ear insertion, and leaf area index) were carried out at time of male flowering stage, while evaluations of grain yield components (number of grains per row, grain yield, and harvest index) carried out during the harvest period. The corn hybrids, AL-Avaré and AL-Bandeirante, independent of experimental site, showed the highest technical efficiency between the rates of 80 to 120 kg ha^{-1} of N. Based on the information obtained in regression analysis verified that Paragominas experiment showed greater vegetative development (plant height, LAI, ear height, number of grains per row, ear length) and higher grain yield compared to corn developed in Capitão Poço experiment.

Keywords: nitrogen fertilization, yield, *Zea mays*

1. Introduction

Corn is of great importance for world agribusiness because it is considered the main constituent in production of animal feed. In addition, currently, its production is increasing, for use in ethanol manufacture (Hage, 2013). Although versatile, corn production has basically followed the growth of pigs and chickens productions, both in Brazil and in the World (Belusso & Hespanhol, 2010).

Brazil is the 3rd largest producer of corn, with an approximate production of 85.5 million tons of grains, in 15.8 million hectares of planted area and grain yield of 5.4 t ha^{-1}, in which Pará state is the main producer in Brazilian Amazon (Conab, 2015).

Among the nutritional requirements of corn crop, nitrogen (N) is the element required in greater quantity and, directly responsible for increase or decrease in grain production. According to Santos, Silva, Carvalho, and Caione (2010), most of Brazilian Amazon soils have insufficient nitrogen contents, requiring fertilizer supply.

The adequate nutritional management for corn crop, although it has been well studied, mainly, nitrogen application (Farinelli & Lemos, 2012; Souza, Buzetti, Tarsitano, & Valderrama, 2012), still needs more studies, since it is one of factors that most affect the corn yield (Melo, Corá, & Cardoso, 2011). According to Goes, Rodrigues, Takasu, and Arf (2013), it is necessary to search for techniques and alternatives that allow the reduction of losses, increasing efficiency in nitrogen application and, consequently, grain yield.

The Brazilian Amazon, shows great aptitude for corn production with climates favorable to crop development, needing information on appropriate rates of N in corn crop in region. The aims of study were to evaluate the effects of applied N rates in topdressing in development and production of corn in Brazilian Amazon.

2. Material and Methods

2.1 Experimental Site

The experiments were conducted under field conditions in Paragominas city (geographical coordinates: 2º59′51″ S and 47º21′13″ W) and Capitão Poço city (geographical coordinates: 1º44′47″ S and 47º3′57″ W), in Brazilian Amazon, State of Pará (Figure 1).

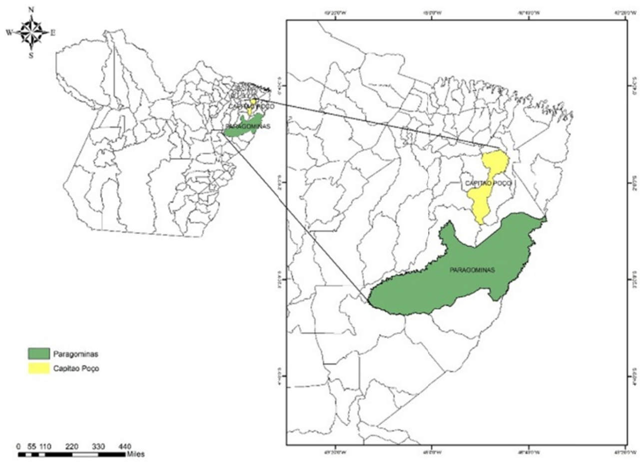

Figure 1. Location map of Paragominas and Capitão Poço city, State of Pará, Brazil

The climate of Paragominas and Capitão Poço, according to Köppen classification, is Am and Ami type (Peel, Finlayson, & McMahon, 2007), respectively. Information on climatic conditions in experimental period is shown in Figure 2.

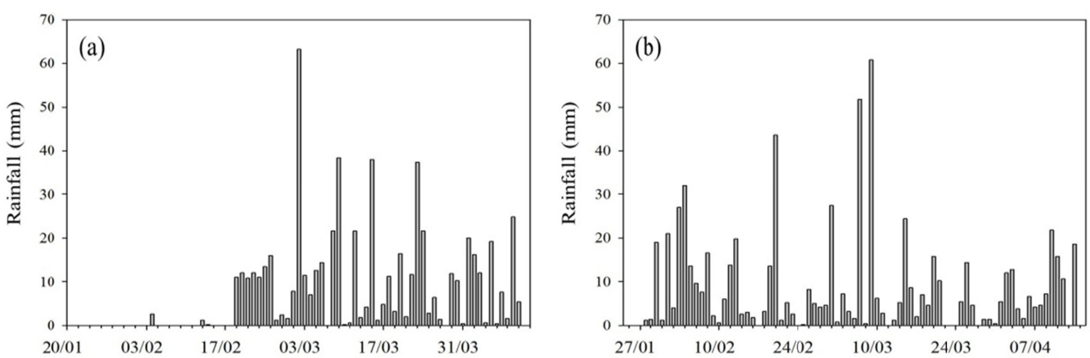

Figure 2. Rainfall during the experimental period in Capitão Poço (a) and Paragominas (b) city, State of Pará, Brazil

The experiments were installed on 20 January 2014 (Capitão Poço) and 24 January 2014 (Paragominas), being that Capitão Poço experiment had a history of lime (*Citrus aurantifolia*) cultivation for 5-years, while the Paragominas experiment was fallow for 2-years.

Sowing fertilization was based on fertilization and liming recommendations for Pará state (Cravo, Viegas, & Brasil, 2010). The mineral fertilizers used for sowing fertilization was NPK (04-20-20), at rate of 333 kg ha^{-1}, applying the fertilizers in planting furrow, below and beside the seeds.

Each experimental plot consisted of five rows of plants, 6.0 m in length, spaced by 0.9 m. The numbers of plants used were 5 plants m^{-1} to obtain a planting density of approximately 55,000 plants ha^{-1}. In all of the experiments, agricultural treatment procedures and plant protection products used were those recommended for corn crops.

2.2 Experimental Design

The experimental design was a randomized block design in a 5 × 2 factorial scheme, consisting of five N rates of topdressing applications (0; 40; 80; 120; and 160 kg ha^{-1} of N) and two corn double hybrids (AL-Avaré; and AL-Bandeirante), with four replicates.

Nitrogen fertilization was carried out manually, applied in topdressing at a distance of approximately 0.08 m from the rows of plants, at V_4 phenological stage (Ritchie, Hanway, & Benson, 1993), using N-urea at rates of 0, 40, 80, 120 and 160 kg ha^{-1} of N.

2.3 Data Collection

The evaluations were performed in components of vegetative development during the period that corn plant was in male flowering stage (V_T phenological stage) (Ritchie et al., 1993). The plant heights (PH) was evaluated by measuring stem length (from the soil surface to base of male inflorescence), while the height of ear insertion (measured from the soil level to first ear) was performed manually, using a tape measure.

In determination of leaf area (LA), five plants of each experimental plot were evaluated, measuring the length (L) and width (W) in cm, to obtain the initial leaf area (LA) (Sangoi, Schmit, & Zanin, 2007). Posteriorly, calculated the leaf area using the following equation:

$$LA\ (m^2) = 0.75 \times W \times L \tag{1}$$

The leaf area index was calculated from leaf area measurements using the following equation:

$$LAI = LA/(e_1 \times e_2) \tag{2}$$

In which, e_1 and e_2 refer to plant spacing in the planting line (m) and between the planting lines (m), respectively.

For the evaluations of grain yield components analyzed the variable number of grains per row, in which ten ears were used per plot, by simple counting of grains present in a row of each ear. After the threshing process, grain yield was obtained by grain mass, determining the water content, corrected to 13% moisture. The harvest index (HI) was calculated as ratio of corn grain dry weight to whole plant dry weight.

2.4 Statistical Analysis

The experimental data for each of the two experimental site were assessed using the Shapiro-Wilks ($p > 0.01$) and Levene ($p > 0.01$) tests to verify the normality and homoscedasticity waste, analysis was performed using SAS statistical software (Sas, 2008). The data were subjected to an individual analysis of variance using the SISVAR statistical software, and relationship between the residual mean square 7:1 was verified. Finally, data were subjected to an analysis of joint variance, in which determined the effects of N rates in topdressing applications were studied by polynomial regression analysis ($p < 0.05$) using the SISVAR statistical software (Ferreira, 2011).

3. Results and Discussion

3.1 Growth and Plant Development Characteristics

The leaf area index of AL-Avaré and AL-Bandeirante hybrids showed statistical differences only in experiment conducted in Capitão Poço. Regarding Paragominas experiment, the average leaf area index was 2.53 and 2.47 for AL-Avaré and AL-Bandeirante, respectively (Figure 3).

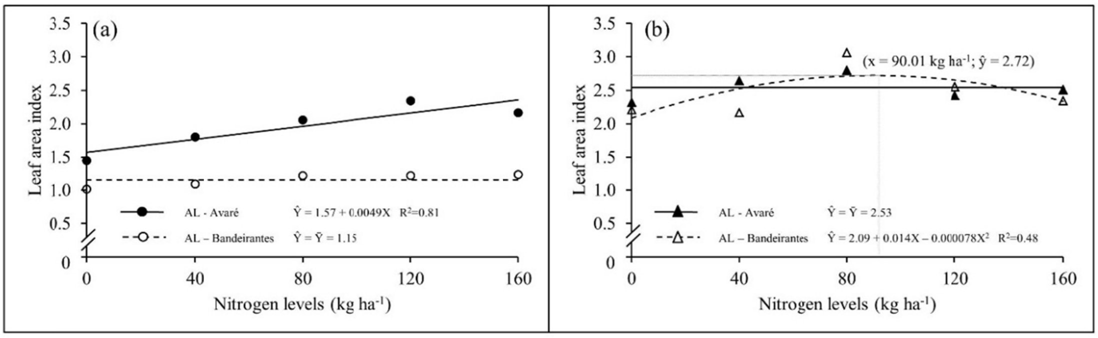

Figure 3. Leaf area index as a function of topdressing applications of N rates (0, 40, 80, 120, and 160 kg ha^{-1} of N) at the V_4 phenological stages in Capitão Poço (a) and Paragominas (b) city, State of Pará, Brazil

The importance of obtaining high LAI values is due to leaves with an adequate N content present an increase in capacity to assimilate CO_2 and to synthesize carbohydrates during photosynthesis, resulting in higher growth and duration of leaf area (Repke, Cruz, Silva, Figueiredo, & Bicudo, 2013).

Thus, it is considered as important component of grain yield the duration of leaf area, which remains physiologically active after the emergence of ears (Castro, Kluge & Sestari, 2008), called "stay green", since it provides the occurrence of photosynthesis for a longer period, resulting in greater availability of carbohydrates for plants (Jiang, He, Xu, Li, & Zhang, 2004; Carmo, Santos, Hagiwara, & Ferreira, 2007).

For the experiment conducted in Capitão Poço, the AL-Ávare hybrid obtained better results for LAI compared to AL-Bandeirante, with mean values of 2.19 and 1.37, respectively.

According to data analyzed, a significant interaction between N rates and corn hybrids (AL-Avaré and AL-Bandeirantes) was observed for plant height variable in experimental sites, Capitão Poço (Figure 4a) and Paragominas (Figure 4b). The corn hybrids grown in Paragominas (Figure 4b) showed higher plant height compared to Capitão Poço (Figure 4a), with the maximum technical efficiency of 229.43 cm obtained in rates of 108.33 kg ha^{-1} of N.

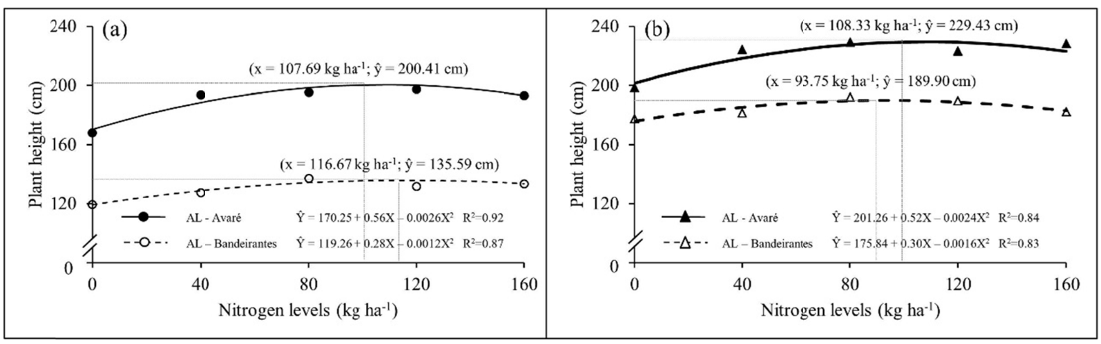

Figure 4. Plant height as a function of topdressing applications of N rates (0, 40, 80, 120, and 160 kg ha^{-1} of N) at the V_4 phenological stages in Capitão Poço (a) and Paragominas (b) city, State of Pará, Brazil

In Capitão Poço experimental (Figure 4a) plants height presented the maximum technical efficiency of 200.41 cm in rates of 107.69 kg ha^{-1} of N, in which AL-Avaré showed higher values. Gomes, Silva, Assis, and Pires (2007) in a study carried out with corn, in Goiás State, Brazil (Red Latosol), verified a significant effect of N rates at plant height, obtaining values of 222 cm in rates of 150 kg ha^{-1} of N. At ear height was observed that AL-Avaré hybrid showed significant interaction, independent of study sites (Figure 5). However, only AL-Bandeirante cultivated in Paragominas experimental (Figure 5b) not showed statistical difference, obtaining a mean ear height of 69.85cm. According to Campos, Silva, Cavalcante, and Beckmann (2010) highest ears height in certain sites, possibly due to local environmental conditions (temperature, humidity and radiation).

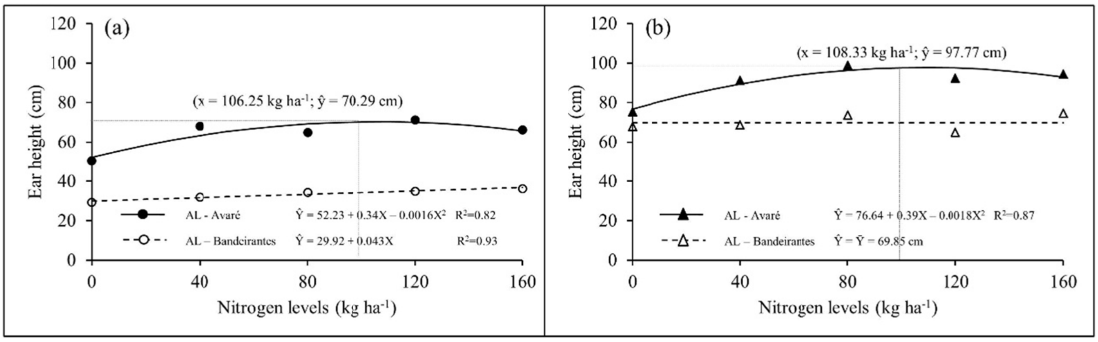

Figure 5. Ear height as a function of topdressing applications of N rates (0, 40, 80, 120, and 160 kg ha^{-1} of N) at the V_4 phenological stages in Capitão Poço (a) and Paragominas (b) city, State of Pará, Brazil

Edaphoclimatic conditions influence in physiological activities interfering directly in grains yield and dry matter. Thus, air temperature has a complex relationship with performance of crop, since optimal condition varies with different stages of growth and plant development (Fornasieri Filho, 2007).

Another important factor in corn development is water deficit, since it can cause damage in phenological stages. In vegetative growth stage, due to lower cell elongation and reduction of vegetative mass, there is a decrease in photosynthetic rate, thus a reduction of 30 to 40% of luminous intensity, for long periods, delays the maturation of grains or causes even a drop in grain production (Fornasieri Filho, 2007).

The stem diameter, regardless of study site, not showed significant interaction (Figure 6). However, Paragominas experimental (Figure 6b) resulted in corn hybrids with higher mean values, AL-Avaré of 16.45 mm and AL-Bandeirante of 18.81 mm.

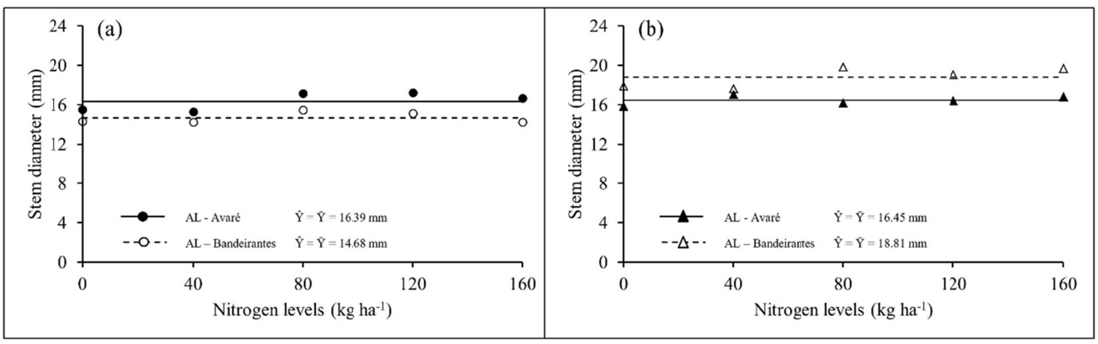

Figure 6. Stem diameter as a function of topdressing applications of N rates (0, 40, 80, 120, and 160 kg ha^{-1} of N) at the V_4 phenological stages in Capitão Poço (a) and Paragominas (b) city, State of Pará, Brazil

For dry matter variable of aerial part of corn, not showed statistical difference (Figure 7). However, a difference was observed in AL-Bandeirante hybrid cultivated in Capitão Poço city (Figure 7a) and Paragominas city (Figure 7b), with mean values of 2.12 and 6.27 t ha^{-1}, respectively.

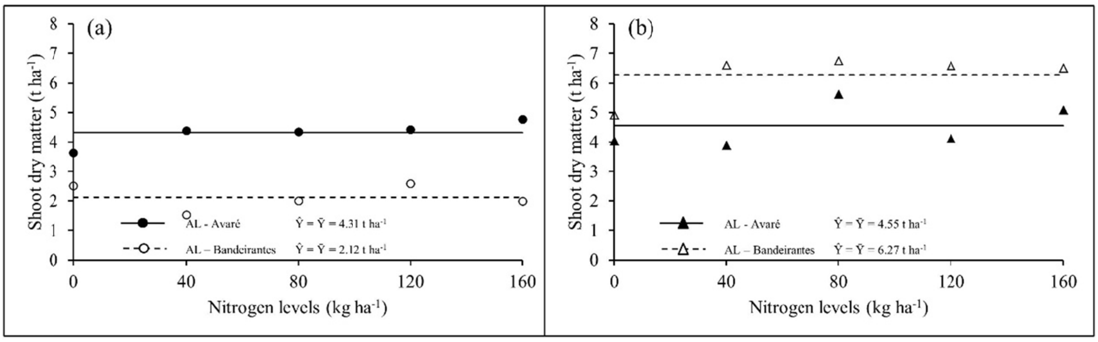

Figure 7. Dry matter variable of aerial part of maize as a function of topdressing applications of N rates (0, 40, 80, 120, and 160 kg ha^{-1} of N) at the V_4 phenological stages in Capitão Poço (a) and Paragominas (b) city, State of Pará, Brazil

3.2 Production Components and Corn Grain Yield

In Figure 8, the ears length in Paragominas city showed an adjustment of the quadratic equation, AL-Avaré ($\hat{Y} = 13.49 + 0.051X - 0.00029X^2$, $R^2 = 0.72$) and AL-Bandeirantes ($\hat{Y} = 11.27 + 0.053X - 0.00027X^2$, $R^2 = 0.92$), with the maximum technical efficiency of 15.73 cm and 13.87 cm obtained in rates of 83.93 and 98.15 kg ha^{-1} of N, respectively (Figure 8b). While, in Capitão Poço city (Figure 8a) not showed statistical difference, with mean values of 12.15 cm for AL-Avaré and 14.31 cm for AL-Bandeirantes.

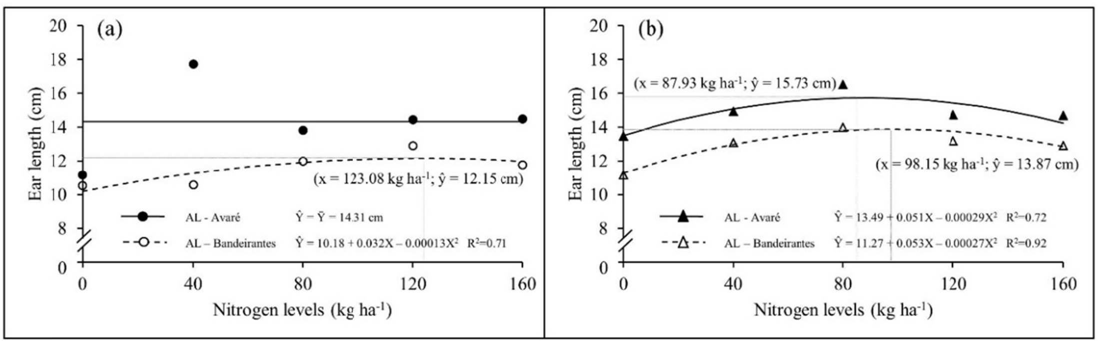

Figure 8. Ear length as a function of topdressing applications of N rates (0, 40, 80, 120, and 160 kg ha^{-1} of N) at the V_4 phenological stages in Capitão Poço (a) and Paragominas (b) city, State of Pará, Brazil

According to Büll (1993), adequate N content in plant promotes greater growth of leaf area and root system, since the nutrient acts in cell division and expansion, and in photosynthesis, showing positive effects on ears length (Gazola, Zucareli, Silva, & Fonseca, 2014), consequently, greater the potential number of grains to be formed per row (Goes, Rodrigues, Arf, & Vilela, 2012).

For the number of rows per ear, corn managed in Capitão Poço city (Figure 9a) and Paragominas city (Figure 9b), showed a significant effect for N rates applied in topdressing, with the maximum technical efficiency of 30.97 and 21.31 rows per ears obtained in rates of 148.94 and 159.04 kg ha^{-1} of N and 30.96 and 30.75 rows per ears obtained in rates of 84.94 and 103.17 kg ha^{-1} of N in Capitão Poço and Paragominas city, respectively. Goes et al. (2013) verified a better fit of quadratic equation ($Y = 15.46 + 0.0414X - 0.0002X^2$), with the maximum technical efficiency of approximately 17.8 rows per spike obtained at rates of 103.5 kg ha^{-1} of N.

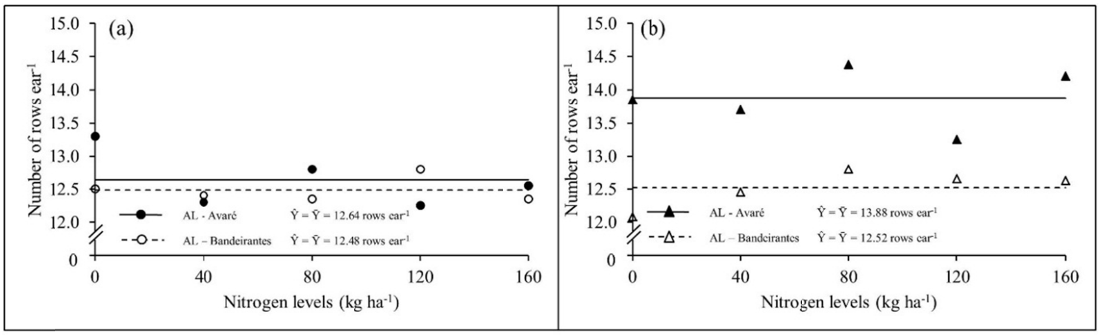

Figure 9. Number of rows per ear as a function of topdressing applications of N rates (0, 40, 80, 120, and 160 kg ha^{-1} of N) at the V_4 phenological stages in Capitão Poço (a) and Paragominas (b) city, State of Pará, Brazil

Grain yield of corn hybrids showed positive responses to nitrogen fertilization at experimental sites (Figure 10), with higher results in Paragominas city (Figure 10b). According to Figure 10b was verified that in Paragominas city the AL-Ávare showed the maximum technical efficiency of 7.09 t ha^{-1} of grains in rates of 93.33 kg ha^{-1} of N ($\hat{Y} = 4.48 + 0.056X - 0.00030X^2$, $R^2 = 0.95$), while AL-Bandeirante presented the maximum technical efficiency of 5.85 t ha^{-1} of grains at rates of 95.74 kg ha^{-1} of N ($\hat{Y} = 4.99 + 0.018X - 0.00009X^2$, $R^2 = 0.56$).

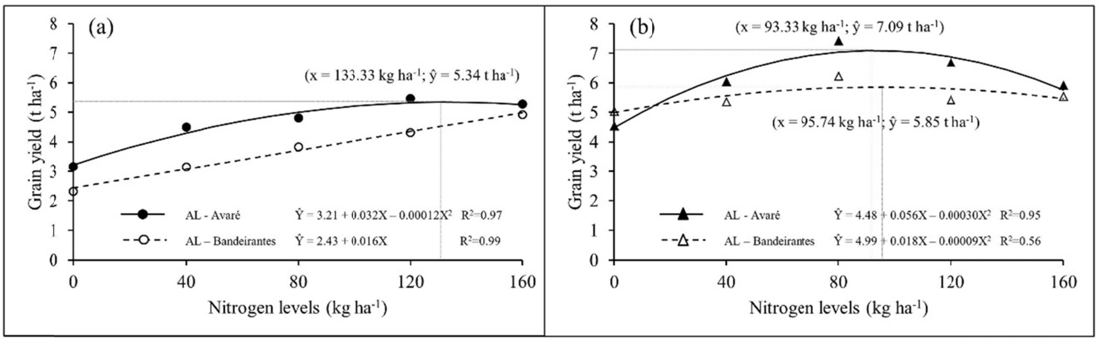

Figure 10. Grain yield as a function of topdressing applications of N rates (0, 40, 80, 120, and 160 kg ha^{-1} of N) at the V_4 phenological stages in Capitão Poço (a) and Paragominas (b) city, State of Pará, Brazil

For the experiment conducted in Capitão Poço city, verified that for AL-Avare ($\hat{Y} = 3.21 + 0.032X - 0.00012X^2$, $R^2 = 0.97$) the maximum technical efficiency of 5.34 t ha^{-1} of grains was obtained in rates of 133.33 kg ha^{-1} of N. For AL-Bandeirante was showed a better linear adjustment ($\hat{Y} = 2.43 + 0.016X$), in which not possible to identify the maximum yield of grains, thus, a higher rates of N provides increases in grain yield (Figure 10a).

The increase in N rates was beneficial until certain rates (except AL-Bandeirante in Capitão Poço city, all hybrids had better yields between 80 and 133 kg ha^{-1}), higher rates promoted a decrease in grain yield, since the efficiency of N rates decreased as a function of their elevation, since it exceeded the crop needs (Fernandes, Buzetti, Arf, & Andrade, 2005). The results founded in the present study are in expected range of N fertilization for corn, according to Cravo et al. (2010) the recommendation of N for corn in Pará State, Brazil, would be 80 to 120 kg ha^{-1} of N.

The harvest index (HI) not showed statistical difference between N rates and corn hybrids, regardless of experimental site (Figure 11). Minuzzi and Lopes (2015) verified a harvest index (HI) of 42% for corn grown in Mato Grosso and Goiás, Brazil, reinforcing the values obtained in present study, which is in range between 46.15% and 63.59%.

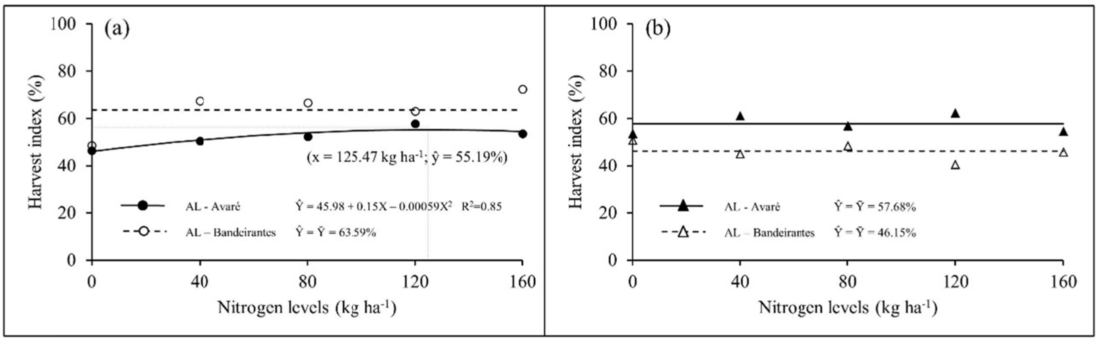

Figure 11. Harvest index as a function of topdressing applications of N rates (0, 40, 80, 120, and 160 kg ha^{-1} of N) at the V_4 phenological stages in Capitão Poço (a) and Paragominas (b) city, State of Pará, Brazil

The harvest index has been used to measure the efficiency of photoassimilates transport to grain (Durães, Magalhães, & Oliveira, 2002), since higher harvest index observed in corn hybrids shows a greater efficiency of converting products synthesized by plant.

The Pearson correlation shows a positive correlation between plant height (PH) and ear height (EH), with r = 0.96**. Plant height influences the amount of dry matter of aerial part, for this reason, correlation between these parameters showed a value of r = 0.53** (Table 1).

Table 1. Pearson correlation coefficients between leaf area index (LAI), plant height (PH), ear height (EH), stem diameter (SD), shoot dry matter (SDM), ear length (EL), number of rows per ear (NRE), grain yield (GY), and harvest index (HI), including all five N rates, the two hybrids and the two locations experiments

	LAI	PH	EH	SD	SDM	EL	NRE	GY	HI
LAI	-	-0.53**	-0.64**	-0.32**	-0.54**	-0.12ns	-0.30**	-0.53**	0.29**
PH		-	0.96**	0.18ns	0.53**	0.48**	0.42**	0.75**	-0.20ns
EH			-	0.24*	0.55**	0.50**	0.40**	0.79**	-0.19ns
SD				-	0.24*	-0.04ns	-0.16ns	0.16ns	-0.19ns
SDM					-	0.31**	0.26*	0.55**	-0.77**
EL						-	0.29**	0.51**	-0.05ns
NRE							-	0.30**	-0.19ns
GY								-	0.04ns

Note. *: significant (p < 0.05); **: significant (p < 0.01); ns: not significant (p > 0.05) by the t test.

From the information in Table 1 was verified a mean correlation between grain yield x shoot dry matter (r = 0.55), grain yield x ear length (r = 0.51), grain yield x plant height (r = 0.75), and grain yield x ear height (r = 0.79). Plant height positively influences most of plant's morphological characteristics in a positive way, and with adequate plant mineral nutrition results in more vigorous, better developed and larger plants, consequently increasing the grain yield, as observed in the PH × GY interaction.

4. Conclusions

Grain yield of corn hybrids showed in Paragominas experiment values of 7.09 t ha^{-1} of grains obtained at rates of 93.33 kg ha^{-1} of N for AL-Avaré, while AL-Bandeirante was 5.85 t ha^{-1} of grains at rates of 95.74 kg ha^{-1} of N.

In Capitão Poço experiment, AL-Avaré showed results of 5.34 t ha^{-1} of grains obtained in rates of 133.33 kg ha^{-1} of N, and AL-Bandeirante showed linear adjustment for the N rates applied in topdressing.

Paragominas experiment showed greater vegetative development (plant height, LAI, ear height, number of grains per row, ear length) and higher grain yield compared to corn developed in Capitão Poço experiment.

The corn hybrids, AL-Avaré and AL-Bandeirante, independent of experimental site, showed the highest technical efficiency between the rates of 80 to 120 kg ha^{-1} of N.

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