RESPONSE OF THE TYPE OF NITROGEN RESOURCE IN THE QUALITY OF MAIZE CULTIVATED IN SOUTHERN AMAZONIA†

[RESPUESTA DEL TIPO DE NITRÓGENO EN LA CALIDAD DEL MAÍZ CULTIVADO EN LA REGIÓN DEL SUR DE LA AMAZONÍA]

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SUMMARY

Nitrogen is the nutrient most absorbed by maize crop and is usually the most limiting for development, especially when it is intended to work with maize cultivars with grain suitability and silage. The experiment was conducted in an experimental area of the Mato Grosso State University, Brazil. The objective of this work was to evaluate the vegetative and productive characteristics of a maize cultivar of dual aptitude as a function of sources and nitrogen doses in the municipality of Alta Floresta-MT, located in the region of the Southern Amazon. The experimental design was a randomized complete block design in a 5x2 factorial scheme. The treatments consisted of the combination of two nitrogen sources (urea and ammonium sulfate) and five nitrogen doses (0, 65, 130, 195 and 260 kg ha^{-1}), with four replicates. For the vegetative characteristics, no nitrogen source effect occurred. Only for plant height and spike insertion occurred a difference between the nitrogen rates used, where they were adjusted to a quadratic regression model with maximum response, respectively, at the doses of 112.5 and 75.0 kg ha^{-1} of N. There was an effect of doses and nitrogen sources on the productive characteristics evaluated.
Keywords: *Zea mays* L.; nitrogen; urea; ammonium sulfate; yield.

RESUMEN

El nitrógeno es el nutriente más absorbido por el cultivo de maíz y, por lo general, es el más limitante para el desarrollo, especialmente cuando está diseñado para trabajar con cultivares de maíz que sean adecuados para el grano y el ensilaje. El experimento se realizó en un área experimental de la Universidad Estatal de Mato Grosso, Brasil. El objetivo de este trabajo fue evaluar las características vegetativas y productivas de una variedad de maíz de aptitud dual en función de las fuentes y dosis de nitrógeno en el municipio de Alta Floresta-MT, ubicado en la región del sur de la Amazonía. El diseño experimental fue un diseño de bloques completos al azar en un esquema factorial 5x2. Los tratamientos consistieron en la combinación de dos fuentes de nitrógeno (urea y sulfato de amonio) y cinco dosis de nitrógeno (0, 65, 130, 195 y 260 kg ha^{-1}), con cuatro repeticiones. Por las características vegetativas, no se produjo efecto fuente de nitrógeno. Solo para la altura de la planta y la inserción de la espiga se produjo una diferencia entre las tasas de nitrógeno utilizadas, donde se ajustaron a un modelo de regresión cuadrática con respuesta máxima, respectivamente, a las dosis de 112.5 y 75.0 kg ha^{-1} de N. Hubo un efecto de dosis y fuentes de nitrógeno sobre las características productivas evaluadas.
Palabras clave: *Zea mays* L.; nitrógeno; urea; sulfato de amonio; rendimiento

INTRODUCTION

In recent years, the corn crop in Brazil has undergone important technological changes, resulting in significant increases in productivity. This increase has been due to the improvement of the genetic material used and the adoption of new technologies aiming at high productivity of green mass and grains, such as balanced fertilization.

In the 2018/19 harvest, 91.65 million tons of corn were produced, which is the record for maize production in Brazil indicating an increase of 13.5% in relation to the 2017/2018 harvest. This increase was mainly due to the increase of 12.16% in the cultivated area (Conab, 2019). However, increased production can also be achieved not only by increasing the area, but also by increasing productivity. The correct management of

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nitrogen fertilization in the maize crop is a strategy to be able to achieve greater production, and this better management, besides the agronomic and economic effect, has an effect on the environment (Ma and Biwas, 2016). Corn is one of the most demanding crops in nitrogen fertilizers, responding very efficiently to this nutrient. According to (Duarte *et al.*, 2017), nitrogen is the mineral nutrient most required by the crop, and it may be limiting in the development of this, and there is a need for complementary nitrogen fertilization. The importance of nitrogen to maize is due to its participation in the composition of related amino acids, protein, chlorophyll and many essential enzymes that stimulate the growth and development of the aerial part and its root system (Malavolta, 2006). According to Rodrigues *et al.* (2018), nitrogen is a nutrient that acts in the vegetative development, directly influencing the cell division and expansion and the photosynthetic process of the plant.

In order to improve the efficiency of nitrogen use, the management of this nutrient has been one of the most studied agricultural practices in this sense. According to Malavolta (2006), this need exists because most of the soil nitrogen is in organic compounds, and this form is unavailable to plants.

Most nitrogen losses occur through denitrification and/or volatilization of the ammonia, especially when the source used is urea. Since the application of the fertilizer on the straw or the soil surface can aggravate the problem. The optimal nitrogen fertilization in the corn crop allows the plant to improve its availability of absorption, synthesize more efficiently the sunlight, and the nutrients offered so that it can develop.

Currently, in Brazil, about 47% of the N is consumed in the form of urea, 20% as ammonium sulfate and 33% as ammonium nitrate (Potafos, 2006). Therefore, the most frequently used nitrogen sources in maize are urea and ammonium sulfate.

Caution should be exercised in recommending the N dose to be used, since if underestimated, it will occur to the reduction of productivity and, when overestimated, reduce the profitability of the producer by the unnecessary expense with fertilizers, besides affecting the environment, as a consequence of N losses due to the excess available (Gomes *et al.*, 2007; Rodrigues *et al.*, 2018). The main mechanisms of loss of nitrogen fertilizers are denitrification, leaching and volatilization. Denitrification and leaching occur in soils under very humid conditions, while volatilization is more common when soils are less moist and dry (Polese et al, 2018). Denitrification is a process classically defined as the microbiological reduction of nitrate to nitrous oxide (N_2O) or molecular N (N_2) by denitrifying bacteria where they comprise about 0.1 to 5% of the total microorganism population of the soils, more than 60 genera have been identified. Volatilization is the loss of nitrogen in the form of ammonia (NH_3) where the nitrogen fertilizer applied to the soil surface is hydrolyzed by the enzyme urease and results in the formation of ammonium carbonate, which decomposes rapidly giving ammonium, bicarbonate and hydroxyl. The leaching process consists in the reduction of N, which is in the form of nitrate (NO^{3-}), in the soil profile to depths below those explored by the roots, which can contaminate groundwater (Vieira *et al.*, 2017). Peña *et al.*, (2001) studied the nitrogen cycle using isotopic techniques (15N) and reported nitrogen losses of up to 90%, emphasizing that the greatest losses occur by leaching, which is closely linked to water management. These losses of fertilizer lead to poor harvests and great economic loss for producers, as well as potential environmental contamination. Corn yield may be reduced because of NH_3-N volatilization. 10 kg ha^{-1} of grain is lost for each 1% of N that is volatilized (Cabezas *et al.*, 2000).

From the economic and environmental point of view, the N dose to be applied is the most important decision in the management of fertilizers in the crop. This recommendation should take into consideration the soil and climatic conditions of the region, cropping system (direct or conventional), sowing season, genetic material responsiveness, crop rotation, season and mode of application, N sources, economic and operational aspects. Ammonium sulphate and urea are the most used nitrogen sources in Brazil, with ammonium sulphate due to the lower losses due to volatilization and urea at lower cost and higher concentration of N (46%). This difficulty of choosing between minimizing losses or optimizing the cost increases the need for research with this intiuito, where Biwas and Ma (2016) commented that little although many studies with nitrogen fertilization in the corn crop, for some regions, is little known on the efficacy of different forms of N fertilizers on corn crop.

The Amazon region, especially the Southern Amazon, has been highlighted in the Brazilian scenario as the most recent and potential agricultural frontier. The opening of land and its exploitation, which was once based on gold and timber extraction, has become an important source of cattle each year and more recently the production of grains, mainly soybeans and corn (Domingues and Bermann, 2012). In this scenario, the large number of small farms where the agriculture and livestock binomial are present, makes the maize crop of dual aptitude important for the success of the activities. Due to the lack of information and appropriate genetic material, especially in the extreme north of the State of Mato Grosso, Brazil, the small local producers have little information and adequate recommendations for the cultivation of maize and its response to managements, including fertilization.

In this context, the objective of this work was to evaluate the productive and vegetative characteristics of maize cultivation of dual aptitude as a function of sources and nitrogen rates in Alta Floresta-MT, Brazil, located in the region of Southern Amazonia.

MATERIAL AND METHODS

The study was developed in an experimental area belonging to the Mato Grosso State University (Unemat), Alta Floresta-MT, Brazil, located at latitude 9º 51 '41.83' 'S, 56º 04' 09.61 " W and altitude of 283 meters. The local soil is classified as Oxisol (Embrapa, 2009).

Before the installation of the experiment, soil samples were collected from the area at depth 0-0.20m and the chemical analysis was performed, and the following results were obtained: pH ($CaCl_2$) = 4.75; P and K (mg dm^{-3}) = 0.7 and 189.5; Ca, Mg, Al and H ($cmol_c$ dm^{-3}) 2.0; 1.1; 0.20 and 4.15; MO = 36 g kg^{-1}, CTC pH7 ($cmol_c$ dm^{-3}) = 7.9; base saturation (V%) = 45.19, clay: 379 g kg^{-1}; sand: 521 g kg^{-1} and silt: 100 g kg^{-1}. Based on the soil analysis, liming was carried out in September, aiming at 60% base saturation increase, where 1.26 Mg ha^{-1} of dolomitic limestone (PRNT - 95%) was applied. The incorporation of the limestone to the soil was carried out with the aid of a plow grating. Soil preparation was performed in a conventional manner through heavy gradation and light gradation. The Table 1 shows the monthly data on precipitation, mean temperature and relative humidity of the air for the conduction period of the research.

The treatments were composed of a combination of two nitrogen sources (urea and ammonium sulfate) and five nitrogen doses (0, 65, 130, 195 and 260 kg ha^{-1}), with four replicates each. The experimental plots consisted of four lines of 5 meters in length, spaced 0.50 m apart. As a useful area, the two central lines were considered, scoring 0.5 m at both ends.

The experiment was conducted in an area previously cultivated with soybean (crop) and corn + *Brachiaria brizantha* cv. Marandú, in the integration system for livestock farming. The basic chemical fertilization in the sowing grooves was calculated according to the chemical characteristics of the soil and taking into account the recommendations of Ribeiro *et al.* (1999) for the maize crop, using the formulated 05-30-10 (N-P_2O_5-K_2O), in the amount of 600 kg ha^{-1}.

Sowing of double hybrid AG 1051 (dual fitness) was performed on November 01, 2011, with the aid of PST2 seeders, regulated to obtain a population of 65,000 ha^{-1} plants. Nitrogen coverage was performed on December 10, in the crop line, without incorporation, according to each treatment, when the plants reached the V4 stage. Phytosanitary treatments were carried out at 10 and 28 days after the emergence of the plants, aiming at the control of *Spodoptera frugiperda*, using the insecticide deltamethrin at the dose of 0.2 L ha^{-1} commercial product (25 g L^{-1} a.i.). Weed control was carried out through two manual weeds at 28 and 42 days after sowing.

On the occasion of the female flowering, in all plots, the leaves were sampled for foliar diagnosis, determining the levels of N, according to Malavolta *et al.* (1997).

The insertion height of the spikes and the mean basal diameter of the stalks were measured at the physiological maturity of the grains, considering the distance between the soil surface and the point of insertion of the main spike, and the diameter of the second stalk, respectively. The components of the production evaluated were the number of grains / row of the spike, number of rows of grain of the spike and mass of one hundred grains. The productivity was obtained from the threshing and weighing of the grains from all the harvested harvests in the useful area of the experimental plots in kg $plot^{-1}$, which was converted to kg ha^{-1} and corrected to 13% moisture.

The data were submitted to analysis of variance with the aid of SISVAR software (Ferreira, 2011), and when significant by the F test, the means of the qualitative factor were compared by the Tukey test, at the 5% probability level and for the quantitative factor , the polynomial regression study was performed.

Table 1. Climatic data from the survey period

Months	Temperature Average (Cº)	Relative Humidity (%)	Monthly Precipiation (mm)
November	25.4	79.3	384.3
December	24.9	79.6	358.8
January	24.8	83.1	312.7
February	24.6	81.1	489.7
March	25.2	80.9	500.1

Font: Climatologic Station - Unemat-Alta Floresta, Brazil

RESULTS AND DISCUSSION

No difference was observed for the characteristics evaluated for the factor sources of urea. As for the nitrogen dose, there was a significant difference for plant height and spike insertion. There was no significant interaction between sources and nitrogen doses for all characteristics evaluated. The Table 2 presents the values of F and the mean values for plant height, height of insertion of the 1st spike. The occurrence of favorable climatic conditions for the crop such as non-elevated temperatures, high relative humidity and constant rainfall (Table 1) may have contributed to the existence of no difference between the N sources used. In the literature we observe researches such as that of Bushong *et al.* (2014) where these authors comment that ammonium sulphate increased grain yield and nitrogen efficiency, while urea and anomic nitrate improved grain yield of irrigated maize. In addition, Biwas and Ma (2016) verified differences between urea and ammonium sulfate to produce corn biomass under no-tillage. The existence of differences between the sources of N is related to the way in which each fertilizer provides nitrogen in the soil to the plants, where when urea is applied to the soil it is rapidly hydrolyzed by the action of urease, an enzyme released by microorganisms, forming NH^{4+} which can be absorbed by plants, immobilized by microorganisms, converted to NO^{3-} by means of nitrification or adsorbed by electrostatic forces to the soil exchange sites. In addition, the rapid transformation of NH^{4+} into NH^3 (g) (ammonia), which is a gas, can be lost to the atmosphere, a phenomenon known as volatilization of ammonia. However, ammonium sulphide loses little nitrogen by volatilization, especially if it is not applied on cultural residues, since, in order to transform NH^{4+} to NH^3 (g), there is a need for a high concentration of OH^- in the medium, the pH of the soil must be high, which is hardly observed in tropical soils (Martins, 2019).

The plant height as a function of the applied nitrogen dose was adjusted to the quadratic model according to Figure 1, the maximum response point being at the dose of 112.5 kg ha^{-1}. According to Ribeiro *et al.* (1999), the recommended dose is 120 kg ha^{-1}, very close to the maximum response in the present study.

The maximum response for ear insertion height was observed at the dose of 112.5 kg ha^{-1}, confirming the response obtained for plant height (Figure 1). The highest plant height (1.68 m) was reached with the estimated dose of 66.8 kg ha^{-1} of N and the maximum insertion height of the first spike (0.82 m), with the application of 70.0 kg ha^{-1} of N, in the form of urea. This is because a plant well nourished in N has better development of leaf area and root system, since the nutrient directly influences cell division and expansion and the photosynthetic process.

Table 2. F values, minimum significant difference (DMS) and mean values for plant height, first ear insertion height, stalk diameter, stalk weight with straw and cob weight without straw from maize plants as a function of different sources and doses of nitrogen.

	N-content Foliar (g kg^{-1})	Plant Height (m)	First Ear Insertion Height (m)	Stalk diameter (mm)
Fonts (F)				
Urea	29.77	1.99	1.18	18.55
Ammonium sulfate	30.22	2.00	1.18	18.36
F values	0.85 ns	0.13 ns	0.00 ns	0.05 ns
DMS Tukey (5%)	1.02	0.05	0.04	1.60
Doses of N (kg ha^{-1}) (D)				
0	29.85	1.94	1.17	18.52
65	30.85	2.07	1.22	17.99
130	29.59	2.04	1.22	19.66
195	30.23	2.00	1.16	18.49
260	29.47	1.90	1.11	17.49 ns
Valor de F	1.04	5.39 **	3.80 *	0.81 ns
F values Linear Regr.		3.48 ns	6.59 *	0.31 ns
F values Quadr. Regr.		18.30 **	8.97 **	1.31 ns
Interaction FxD				
F values	0.95	1.06 ns	0.65 ns	0.04 ns
Coefficient of variation	5.15	4.04	5.60	13.44

*, ** and ns: correspond respectively to significant at 5%, 1% and not significant by the F test.

The differences between levels of nitrogen responses in corn crop may be related to soil class, predecessor crop, climatic conditions and sowing season. Considering that the area of the present research had a medium organic matter content (36 g kg^{-1}) and previously it was cultivated with the soybean crop and with maize in a consortium with brachiaria, it also had a large volume of straw that was incorporated to the soil and a good N availability provided by the predecessor crops, a fact that may explain the non-response of the doses to various evaluated characteristics. In addition to this information, Charlotte and Hobbie (2016) verified in a long-term study that the addition of N to the soil decreased the decomposition rate and the carbon accumulation, due to a decrease in the oxidative enzymatic activity of the microbial community, or the higher the N addition to the soil, the smaller the decomposition will be.

In agreement with this research, Villetti *et al.* (2015) did not verify the effect of the application of different sources (ammonium sulfate, urea, ammonium nitrate and formulated nitrogen on the stem diameter of irrigated maize.

Although there was no significant response of sources and doses of nitrogen to the diameter, the stem of the corn acts as a reserve structure, translocating photoassimilates from the stalk to the grains. The ear diameter can influence the quality of the silage, because when the ear diameter is reduced, it also reduces the amount of grain of the ears (Kaplan *et al.*, 2011).

Although there was no significant difference between doses and sources of nitrogen for stalk diameter, steer and straw weight, there was a trend of higher response at the dose of 130 kg ha^{-1}, indicating how at plant height and spike insertion, that the ideal dose is close to this. These results are similar to those verified by Biwa and Ma (2016) where these authors verified that doses above 150 kg ha^{-1} did not cause an increase in the vegetative characteristics (biomass).

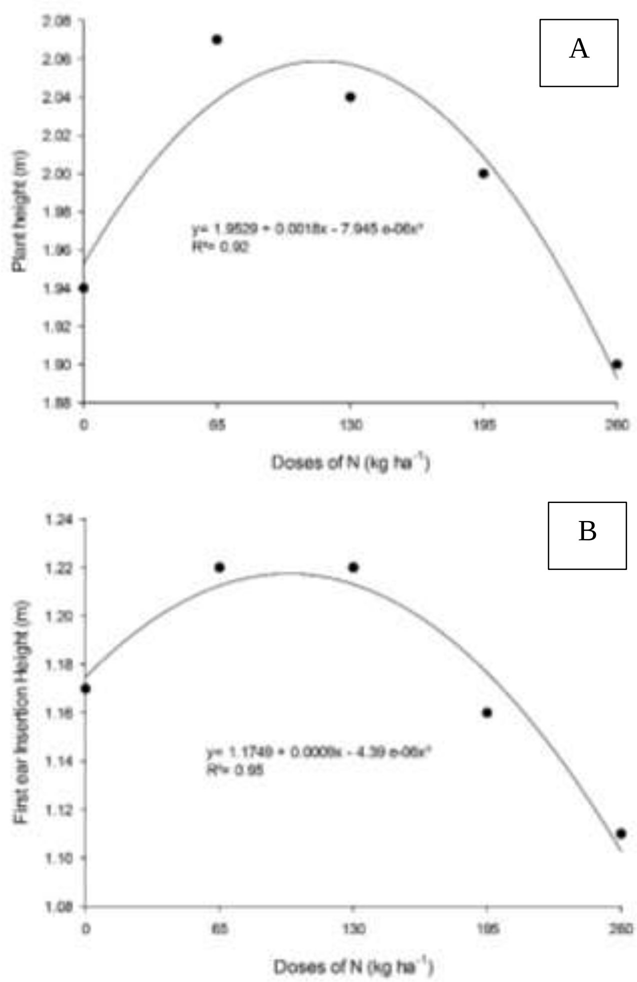

Figure 1. Plants Height (A) and first ear insertion height (B) as a function of doses of nitrogen.

The Table 3 shows the values of F, minimum significant difference and mean values of ear length, number of rows of grains and number of grains per row of maize as a function of sources and doses of nitrogen applied. For none of the characteristics evaluated, there was a significant difference for source, doses and there was also no significant interaction between these factors.

Spike length, number of grains per spike and number of grains per row are characteristics that help identify the occurrence of adverse conditions to the good development of the plant, especially when they occur between the phenological stages of definition of cob diameter and spike size, and the flowering period, after the exteriorization of the tassel and the stigmas of the spike, associated with the definition of the number of grains per spike (Hanway, 1963).

According to Fancelli (2015), the nutrient deficiency at these stages can seriously reduce the potential number of seeds, as well as the size of the ears to be harvested due to the number of eggs and the size of the spike are defined in phase V12, thus indicating that in the present work, maize plants, regardless of the treatment used, were adequately nourished in relation to nitrogen. In this sense, Dhital and Raun (2016) commented that the absorption of N by maize is very affected by the climatic conditions of each year of cultivation, which can influence the dose and the application time.

The values of F, minimum significant difference and mean values of ear diameter, mass of 1000 grains and corn yield as a function of nitrogen sources and doses are presented in Table 4. For all the characteristics, no significant effect of sources and doses, as well as significant interaction between these factors.

Regarding the spike diameter, there are results in the literature that diverge in relation to the response to the application of different sources and nitrogen doses. For Kappes *et al.* (2009), nitrogen sources showed significant influence (urea, ammonium sulphate and Entec®), with the highest values being observed with the use of Entec®, however this was only different from the control. Already Galindo *et al.* (2015) studying sources (Urea and Super N) and doses of nitrogen with and without the application of *Azospirillum brasilense*, in cerrado area, did not verify difference between the two sources for maize productivity, corroborating with the present work in relation to there is no difference between N sources. Still, Martins *et al.* (2017) studied the influence of nitrogen doses in the form of urea, in surface cover applied when the plants had three completely expanded leaves, that nitrogen did not significantly affect ear diameter.

Table 3. Productive characteristics. (Length of spike, number of rows of grains and number of grains per row) of maize beds depending on different sources and doses of nitrogen).

	Ear Length (cm)	Number of rows of grains	Tang weight with straw (g)	Spike weight without straw (g)
Fonts (F)				
Urea	13.6	14.6	214.5	196.3
Ammonium sulfate	13.8	14.6	210.6	186.3
F values	0.10 ns	0.06 ns	0.08 ns	0.62 ns
DMS Tukey (5%)	1.25	0.38	28.07	26.84
Doses de N (kg ha^{-1}) (D)				
0	12.8	14.8	185.3	165.2
65	13.5	14.7	205.1	197.0
130	14.8	14.9	238.6	210.9
195	14.1	14.2	221.3	192.5
260	13.5	14.4	211.3	191.2
F values	1.26 ns	2.04 ns	1.67 ns	1.28 ns
F values Regr. Linear	0.85 ns	3.32 ns	1.98 ns	1.06 ns
F values Regr. Quadr.	3.30 ns	0.05 ns	3.70 ns	3.24 ns
Interation FxD				
F values	0.31 ns	1.75 ns	0.26 ns	0.54 ns
Coefficient of variation (CV%)	14.08	4.01	20.35	21.58

*, ** and ns: correspond respectively to significant at 5%, 1% and not significant by the F test.

The bulk of a thousand grains, an important component of grain yield in maize, was not influenced by nitrogen doses and sources, agreeing with data from Souza and Soratto (2006), that there was no significant difference between urea and Entec®, for mass of one hundred grains. Silva *et al.* (2015), studying nitrogen levels in maize, also did not verify a change in this characteristic, obtaining an average value of 27.5 g, slightly below that observed in the present study. For Borrás and Otegui (2001), this is the production component less affected by variations in management practices and fertilization.

Kappes *et al.* (2009), testing the sources and time of application of nitrogen verified that the applications of urea, ammonium sulphate and Entec® provided the highest yields, differing significantly from the control. The authors argue that the results show that maize productivity, even when sowed in succession to soybean, can be increased with nitrogen fertilization in coverage. In the present study, among the sources, there was no significant difference. Souza and Soratto (2006) also did not obtain difference between urea and Entec®, for grain yield.

Soratto *et al.* (2010), verified that the application of N in the form of ammonium sulphate provided higher grain yield, in relation to amiréia, however, did not differ from other sources. Kappes *et al.* (2009) observed a significant increase in corn yield with application of 70 kg ha^{-1} of N, regardless of the source used (ammonium sulfate, urea and Entec®). Meira *et al.* (2009) did not verify the effect of these sources on irrigated maize productivity.

Galindo *et al.* (2015) commented that high maize productivity was obtained mainly at the highest doses studied (100, 150 and 200 kg ha^{-1} of N) due to the high demand of the planted hybrid and also to the maize plantiation 15 days after incorporation to the soil of a grass with high C/N ratio, which caused immobilization of soil nitrogen, results not verified in the present work. This difference between the results was due to the environmental differences between the two research sites.

As seen previously several factors can affect the availability of nitrogen in the soil. According to Zhou *et al.* (2014) soil N enrichment often decreased microbial decomposition and soil respiration especially for litter decomposition and materials with high C/N ratio (Riggs *et al.*, 2015). Thus, it is evident that tests in different cultivation conditions and fertilizations. The productive results and information on the phenological response of maize with dual aptitude, when cultivated in the climatic conditions of Southern Amazonia, justifies the development of new researches and the accomplishment of tests to verify the Value of Culture and Use (VCU) in this important agricultural frontier region of Amazonia.

Table 4. Productive characteristics (ear diameter, mass of 1000 grains and productivity) of maize plants in function of different sources and nitrogen rates.

	Number of grains per row	Ear diameter (mm)	1000 Grain Mass (g)	Productivity (Kg ha^{-1})
Fonts (F)				
Urea	33,2	49,4	323,8	7,792
Ammonium sulfate	32,4	49,0	294,0	7,895
F values	0,51 ns	0,33 ns	3,26 ns	0,02 ns
DMS Tukey (5%)	2,52	1,57	33,85	908,35
Doses of N (kg ha^{-1}) (D)				
0	30,5	48,0	290,3	7357
65	31,9	49,1	323,0	7623
130	35,2	50,0	311,9	8921
195	33,4	49,3	323,6	7701
260	33,0	49,6	291,9	7516
F values	1,67 ns	0,75 ns	0,77 ns	1,60 ns
F values Regr. Linear	2,33 ns	1,59 ns	0,005 ns	0,06 ns
F values Regr. Quadr.	2,92 ns	0,88 ns	2,34 ns	3,41 ns
Interaction FxD				
F values	1.11 ns	0.71 ns	0.99 ns	0.42 ns
Coefficient of variation (CV%)	4.01	4.93	16.89	20.23
	11,85	4,93	16,89	17,88

*, ** and ns: correspond respectively to significant at 5%, 1% and not significant by the F test.

CONCLUSIONS

There is no difference between the nitrogen sources studied para todas as características avaliadas. As for the nitrogen doses, there is difference only for plant height and height of spike insertion, and the dose of 112.5 kg ha^{-1} is the point of maximum response for both characteristics

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