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Characteristics of maize production irrigation and time-varying doses of nitrogen

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Maize grown during the off season is a viable alternative for the state of Mato Grosso, Brazil. Therefore, the objective of the present study was to investigate the influence of the duration of irrigation with nitrogen doses on the yield characteristics of maize. The experiment was conducted in a greenhouse using a randomized completely block design with a factorial 5×5 matrix corresponding to 5 irrigation durations, the soil water tension at 15, 25, 35, 45 and 55 kPa and five doses of nitrogen (0, 50, 100, 150 and 200 mg dm^{-3}), with four replications. The experimental units were represented by plastic pots with a capacity of 18 dm^{3} of soil. We evaluated the productive characteristics of the maize plant. The data were submitted to the F test and polynomial regression. The increased dry mass of the shoot, the root dry mass and the ear length were obtained from the plant under irrigation when the soil reached a 15 kPa tension at doses of 100 and 150 mg dm^{-3} of nitrogen. For the weight of 100 grains, no interaction between the factors was found, providing a greater grain yield with 15 kPa and 200 mg dm^{-3} of nitrogen alone.

Key words: *Zea mays* L., tensiometer, nitrogen fertilization.

INTRODUCTION

Due to the global importance, maize (*Zea mays* L.) is one of the most studied plant species. In constantly seeking improvement, programs seek more productive and economically profitable varieties (Carvalho et al., 2008). In many breeding programs, cultivars with additional resistant to water stress and greater efficiency in the use of nitrogen are desired. According to Amin (2011) the crop has a wider range of uses including: human food, industrial processed food production of starch and used as forage to feed animals.

Maize has undergone major changes in management and cultivation in Brazil, which have resulted in significant increases in the grain yield (Von Pinho et al., 2009). Despite these transformations, Brazil still presents a low average productivity (3,620 kg ha^{-1}) compared to that of China (5,560 kg ha^{-1}) and the U.S. (9,660 kg ha^{-1}) (Agrianual, 2011).

The key to enabling increased production is irrigation management, which consists of determining when and with how much to irrigate (Bernardo et al., 2006).

Irrigation management aims to meet the water requirement of the crop without deficit or excess (Gomes

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Table 1. Chemical and textural characteristics of oxisol collected from 0.0-0.20 m in an area of Cerrado vegetation.

Characteristics	Value
Particle size distribution (g kg^{-1})	
Sand	496
Silt	83
Clay	421
pH ($CaCl_2$)	4.0
Phosphorus (mg dm^{-3})	1.1
Potassium (mg dm^{-3})	22
Organic matter (g dm^{-3})	12.8
Calcium + Magnesium (cmolc dm^{-3})	0.3
Calcium (cmolc dm^{-3})	0.2
Magnesium (cmolc dm^{-3})	0.1
Aluminium (cmolc dm^{-3})	0.9
Hydrogen (cmolc dm^{-3})	2.8
Sum of base (cmolc dm^{-3})	0.4
Cation exchange capacity (cmolc dm^{-3})	4.3
Bases saturation (%)	8.9
Aluminium saturation (%)	77.4

and Testezlar, 2004).

The productivity of maize under water deficit may be higher or lower than normal, depending on the intensity and timing of water stress (Cunha and Bergamaschi, 1992). Moreover, maize progressively responds to fertilization because the other factors are at optimum levels, and nitrogen is the nutrient that elicits the greatest response with regard to increasing the grain yield (Biscaro et al., 2011). However, the rational use of nitrogen fertilizer is critical, not only to increase production but also to decrease the cost of production (Fageria et al., 2007).

The monitoring of the soil moisture in the root zone of greatest activity has been recommended to verify the effectiveness of irrigation (Azevedo and Silva, 1999). This monitoring is necessary because dry soil cannot supply enough power to meet the growing needs of the crop (Wolfe et al., 2008), directly affecting the production.

Water, being one of the most essential factors for agricultural production, should be used rationally because its lack or excess significantly affects crop yields, making appropriate management necessary to maximize production (Morais et al., 2008) and decrease production costs. Therefore, the objective of this study is to verify the productive characteristics of maize as influenced by irrigation and nitrogen fertilization in the soil of the Brazilian Cerrado.

MATERIALS AND METHODS

The experiment was conducted from March to June 2012 in a greenhouse at the Institute of Agricultural Science and Technology, Federal University of Mato Grosso (UFMT), Campus of Rondonópolis, in the city of Rondonópolis-MT, which is located at an altitude of 281 m, 16°28’17’’S latitude and 54°28’17’’W longitude, with an Aw climate type, Köppen classification.

The experimental design was a randomized block in a 5×5 factorial scheme with four replications. The treatments consisted of five durations of irrigation, five soil water tensions (15, 25, 35, 45 and 55 kPa) and five doses of nitrogen (0, 50, 100, 150 and 200 mg dm^{-3}), totaling 25 treatments for a total of 100 plots. The experimental units were represented by plastic pots with a capacity of 18 dm^3 of soil.

During the experiment, the average temperature and relative humidity inside the greenhouse were 28.65°C and 73.8%, respectively.

The soil was collected from an area of Cerrado vegetation that is classified as Dystrophic Red sandy loam texture (Embrapa, 2006), and the 0.0 to 0.20 m layer was passed through a 4 mm aperture sieve and homogenized for insertion into the experimental units. A soil chemical analysis showed the following chemical characteristics (Table 1). The base saturation increased to 60% (Sousa and Lobato, 2002), applying limestone and incubating in the soil for 30 days to maintain the soil moisture at 60% of the field capacity.

Tensiometers were installed at a 0.20 m depth, near the effective area of the root system and near the center of the vessel using an auger screw. Five tensiometers were installed in each block, totaling 20 monitoring units. The tensiometers were installed in the treatments with a nitrogen rate of 100 mg dm^{-3} (reference dose) (Figure 1), which was used as an indicator of the duration of irrigation and the irrigation duration for each analyzed tension (15, 25, 35, 45 and 55 kPa).

The soil water retention curve was analyzed in the laboratory of hydraulic UFMT, Campus Rondonópolis, MT, Brazil. The soil was collected randomly in the very experimental unit using a volumetric ring (ring Köpeck) and subjected to low tension, the voltage and extraction chamber Richards table and high tension (Libardi, 2005). The retention results were interpolated by the Van Genuchten

Figure 1. Overview of maize experiment in a greenhouse at 21 days after plant emergence.

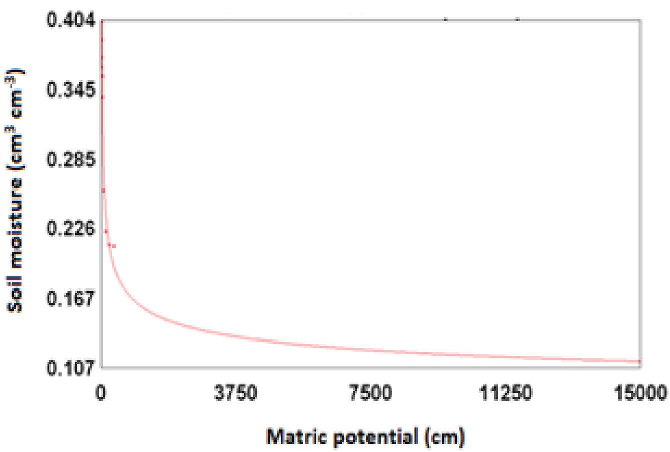

Figure 2. Water retention curve.

equation (Equation 1) (Figure 2) using the computer program Soil Water Retention Curve (SWRC, version 3.0), which was developed by Dourado Neto et al. (2000).

$$\theta = \frac{0.468}{[1+(0.0573\,|\Psi m|)^{0.3848}]^{0.8724}} \quad (1)$$

θ is the soil moisture ($cm^3\ cm^{-3}$); Ψm is the soil water tension (cm).

The soil water tension during irrigation was monitored using a digital tensiometer with a sensitivity of 0.1 kPa. The duration and the volume of irrigation water replacement were defined based on the evaluation of the soil water tension. The irrigation was performed after three tensiometers for each of the four existing tension treatments reached their limits.

The volume of water that was applied by irrigation was calculated based on the soil-water retention curve, and all of the irrigations increased the soil moisture at field capacity (10 kPa) as in Bernardo et al. (2006).

With the observed tensions, the corresponding humidities were calculated from the retention curve. With these values and the corresponding moisture at field capacity, the volume replacement was calculated (Equation 2).

$$V = (\theta cc - \theta f) \times 18{,}000 \quad (2)$$

V is the volume of water, (cm^3); θcc is the soil moisture at field capacity ($cm^3\ cm^{-3}$); θ*f* is the moisture from the retention curve according to the observed tension ($cm^3\ cm^{-3}$).

The maize crop was fertilized using 160 mg dm^{-3} of phosphate fertilizer (P_2O_5) and 75 mg dm^{-3} of potassium fertilizer (K_2O), using as sources the simple superphosphate and potassium chloride, respectively, as adapted from Bonfim-Silva et al. (2011).

The plants were fertilized with micronutrients 17 days after plant emergence (DAPE) according Bonfim-Silva and Monteiro (2010) using 1.39 mg dm^{-3} of H_3BO_3 (boric acid), 2.61 mg dm^{-3} of $CuCl_2.2H_2O$ (copper chloride dihydrate), 2.03 mg dm^{-3} of $ZnCl_2$ (zinc chloride) and 0.36 mg dm^{-3} of MoO_3 (molybdic acid).

In nitrogen fertilization, urea was applied in solution form and split into three applications: 50% with 5 to 7 fully expanded leaves, 25% with 9 to 12 fully expanded leaves and 25% with 16 fully expanded leaves.

The maize hybrid that was used in the experiment was DKB 390 PRO, which is classified as a simple hybrid with early maturity, high thatched sanity and good lodging resistance and grain production.

The seeds were sown on February 28, 2012 with five seeds per pot at a depth of 5 cm. The first thinning rushed 4 DAPE leaving two plants for pot. At 11 DAPE, the first nitrogen fertilization was performed with 50% of the doses of each treatment, and after the second thinning, leaving only one plant per pot. From planting until 32 DAPE, the soil was maintained at 10 kPa (field capacity), and the treatments with tension measurement began in this period. The tensions were monitored twice daily, in the morning and afternoon. Following each reading, irrigation was performed, when necessary, by hand watering.

The plants were harvested at R6 stage of physiological maturity of maize at 122 DAPE, when all of the plants were already in the process of natural senescence of the finalized leaves.

We evaluated the dry mass of the shoot (DMS), which included the dry mass of the leaves, dry mass of the stalk, dry mass of the tassel and dry mass of the cob. After the insertion of the material in an oven at 65°C to constant weight, the obtained material was analyzed. For the root dry mass (RDM), the roots were washed, dried for 24 h and later placed in paper bags, identified and transferred to the stove to a constant mass at 65°C and further verified by digital scales. The insertion of the first spike (FS) was verified from the ground up to ear height in the stem. The spike length (SL) was measured using a millimeter ruler, and before weighing to determine the weight of 100 grains, the moisture was adjusted to 13%.

The data were subjected to an analysis of variance by the F test and were found to be significant when, in the regression analyses, a 5% probability was found using the Sisvar program (Ferreira, 2008).

RESULTS AND DISCUSSION

There was an interaction between the nitrogen and the duration of irrigation in the dry mass of the shoots of maize. During irrigation (water tension in the soil), doses of 50, 100 and 150 mg dm^{-3} of nitrogen were significant, adjusting to the decreasing linear regression model (Figure 3). The largest decrease in the dry mass of the shoots occurred at a dose of 100 mg dm^{-3} of nitrogen, with a 39.62% loss in the dry mass of the shoots under irrigation occurred when the soil reached 15 to 55 kPa. The same nitrogen rate increased dry mass of the shoots with 251.10 g $plant^{-1}$ when the irrigation reached 15 kPa.

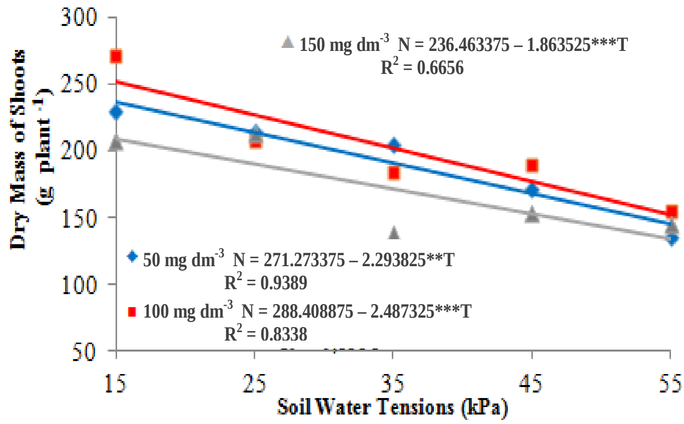

Figure 3. Dry mass shoots maize according to the tensions soil water mass at doses of nitrogen 50, 100 and 150 mg dm^{-3}. N - Nitrogen. T – Tension. ***, ** Significant at 0.1 and 1%, respectively.

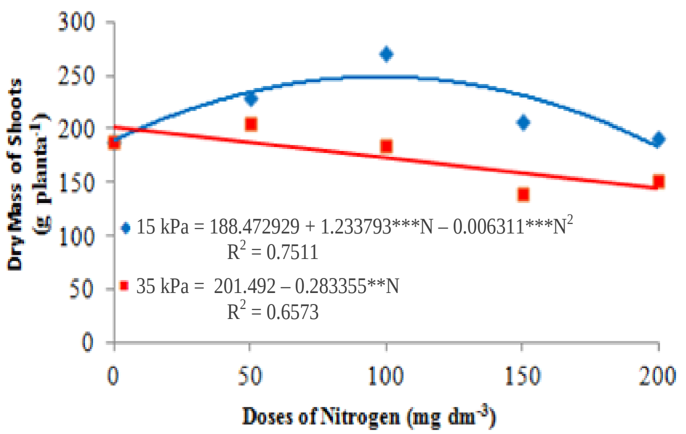

Figure 4. Dry mass of shoots maize according to the doses of nitrogen, in soil water tensions of 15 and 35 kPa. N – Nitrogen. ***, ** Significant at 0.1 and 1%, respectively.

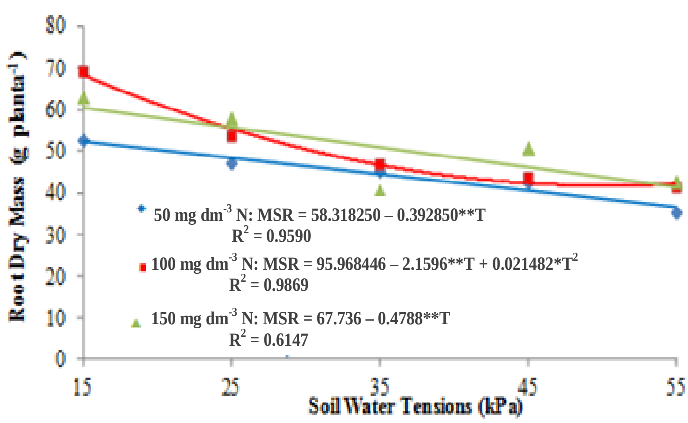

Figure 5. Root dry weight maize according to the tensions soil water mass at doses of nitrogen 50, 100 and 150 mg dm^{-3}. T – Tension. N - Nitrogen. **, * Significant at 1 and 5%, respectively.

There was a reduction of 38.74 and 35.75% of the dry mass of shoots at doses of 50 and 150 mg dm^{-3} of nitrogen, respectively, the shortest irrigation interval (15 kPa) for the largest range of evaluated irrigation (55 kPa). Therefore, it appears that smaller strains showed the highest production of dry mass in the aerial parts of the maize, demonstrating the importance of maintaining the moisture level close to field capacity. These results agree with those obtained by Guimarães et al. (2012), which verified the reduction in the total dry mass under water deficit in the three growth stages of maize, lasting 40 days at the vegetative stage, 75 days at the flowering stage and 52 days at grain filling stage. Nascimento (2008) observed an increase of 33.3% in the dry mass of the shoots of sorghum that were treated with greater water availability in the soil (field capacity) compared to treatment with a lower availability of soil water (40% of the field capacity). Pegorare et al. (2009) also found that the dry mass of the shoot was adjusted to the linear regression model, increasing with higher water levels in the soil for the maize crop.

Irrigation was performed when the soil reached the tensions 15 and 35 kPa, which were significant in the unfolding of nitrogen in the dry matter production of the shoots (Figure 4). The lowest pressure (15 kPa) at the beginning of irrigation was adjusted to the quadratic regression model, with the increased dry mass of the shoots (248.77 g), which occurred at a dose of 97.75 mg dm^{-3} of nitrogen. When the irrigation was performed at the time that the tension reached 35 kPa, the treatment without nitrogen fertilization produced higher growth in the shoots (201.49 g), with a decrease in the dry matter production of the shoots of 28.13% for the highest dose of applied nitrogen (200 mg dm^{-3}).

Galvão et al. (2009) found that the levels of nitrogen in the dry mass of the shoots were not significantly reduced when this nutrient was applied for a longer duration and are in the range that is considered adequate for maize in an oxisol. However Safari et al. (2014) testing doses 0 to 250 kg ha^{-1} observed that the dry weight increase linearly until the last dose. Carvalho et al. (2011) evaluated the maize response to the DBK 390 nitrogen, which fit to a linear model, with the increased dry weight of the shoots when subjected to a dose of 160 kg ha^{-1}. The photosynthetic activity and consequently the dry matter production can be determined by the level of available nitrogen (Jeuffroy et al., 2002).

The root dry weight also showed a significant interaction between the evaluated factors. In the analysis of the unfolding of soil water tension for nitrogen levels, the doses of 50, 100 and 150 mg dm^{-3} of nitrogen significantly influenced the root dry mass (Figure 5). At a nitrogen dose of 50 mg dm^{-3}, its interaction with the water tension in the soil for the duration of irrigation in the dry root mass of the maize was fit to a decreasing linear regression model, exhibiting a decrease of 29.97% in the dry mass of the roots when comparing treatments at

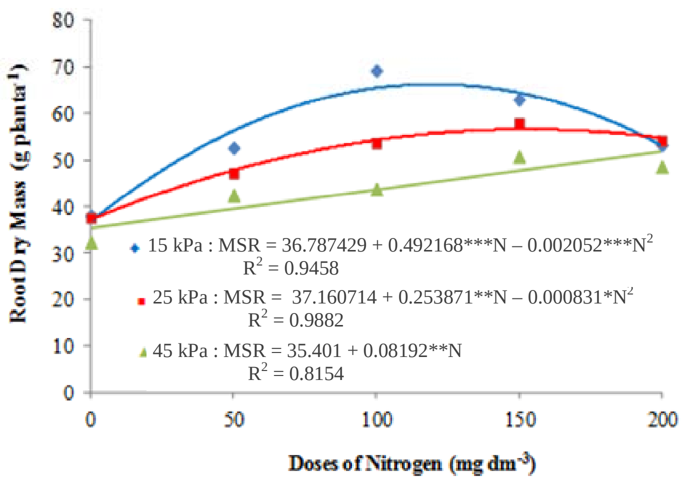

Figure 6. Root dry mass maize according to the doses of nitrogen, in soil water tensions of 15, 25 and 45 kPa. N – Nitrogen. ***, **, * Significant at 0.1, 1 and 5%, respectively.

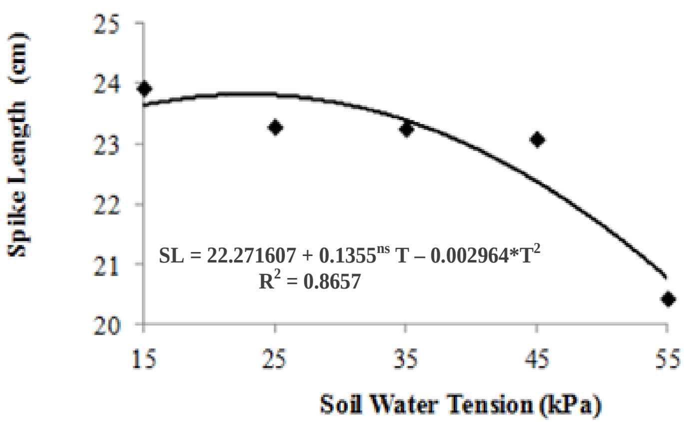

Figure 7. Spike length (SL) maize according to the soil water tension (kPa). T-Tension. ns Not Significant. * Significant at 5%.

higher voltages, which yielded the lowest production of the root dry mass. The dose of 150 mg dm^{-3} of nitrogen was adjusted to the decreasing linear regression model, experiencing a decrease of 31.63% in the dry mass of the root from the lowest to the highest rated voltage. The increased dry mass of the roots was obtained at a nitrogen dose of 100 mg dm^{-3}, with an interaction of 15 kPa tension at the beginning of irrigation, producing 68.41 g, but when independent of fertilizer applied, the best results of the root dry mass were provided when the plant was subjected to irrigation when the soil water tension reached 15 kPa.

Conte et al. (2009) found no significant effect on the root dry mass in irrigated and non-irrigated maize, and the authors attributed this result to the high coefficient of variation of 36.0%. Analyzing the results of the soil water stress for irrigation in relation to fertilization with nitrogen for the production of the root dry mass of maize, only the voltages of 15. 25 and 45 kPa were significant (Figure 6).

Analyzing the treatment which irrigated to the proper tension of 15 kPa, the values were fit to the quadratic regression model, with the highest production (66.30 g) observed when applied to 119.92 mg dm^{-3} of nitrogen; after this dose, the production reduced. Only 45 kPa irrigation fitted to the growing linear regression model, providing a 31.64% increase in the dry root mass when comparing the treatment without nitrogen fertilization with the highest applied dose (200 mg dm^{-3}). Soares et al. (2009) found no significant difference in the overall mean root dry mass between two nitrogen doses (0 and 2 mmol L^{-1}) for six inbred maize in nutrient solution. Sangoi et al. (2009) analyzed four doses of nitrogen in various soil types and found in most soils that the highest dose, 200 kg ha^{-1}, provided the lowest root growth.

The insertion of the first spike did not influence the nitrogen and irrigation duration, which varied independently between 107 and 140 cm, possibly an intrinsic characteristic of the hybrid DKB 390 PRO. Casagrande and Filho (2002) also found no difference in the insertion of the spike and nitrogen rates (0, 30, 60 and 90 kg ha^{-1}) in the form of urea. According to Siqueira et al. (2009), the insertion of the spike contributes greatly to the layering and occurs because the higher the plant is, the more susceptible it is to lodging. However, Campos et al. (2010), in verifying the relationship between plant height and ear insertion with bedding plants and breaking forty-nine commercial cultivars in five regions found no relationship between the plant height and the ear insertion rates with lodging.

For the spike length, the effect of irrigation duration and nitrogen were isolated, both of which fit within the quadratic regression model. Regarding the tensions, the largest ear length (23.82 cm) was obtained when the irrigation began with a tension of 22.86 kPa (Figure 7). Silva et al. (2012) in evaluating various genotypes of maize under severe water stress found that the spike length ranged from 12.8 to 9.05 cm among 36 genotypes. In agreement with the results of Blanco et al. (2011) using the hybrid AG1051, the ear length is set in a linear way with irrigation up to 220% of the reference evapotranspiration (ETo), 24.8 cm long.

Analyzing the nitrogen doses, the maximum spike length (24.06 cm) was provided by the dose of 143.91 mg dm^{-3} of nitrogen (Figure 8).

These results corroborate those of Ferreira et al. (2010), who also observed a quadratic response for this variable to the nitrogen dose of 250 kg ha^{-1}. However, Mendonça et al. (1999) in evaluating doses of nitrogen from 48.79 to 319.47 kg ha^{-1} found that higher doses produced the greatest ear lengths and adjusted to a linear regression model. The average length of the cob can interfere directly with the number of kernels per row and, consequently, the corn yield (Kappes et al., 2009). It is therefore important that the assessment is performed.

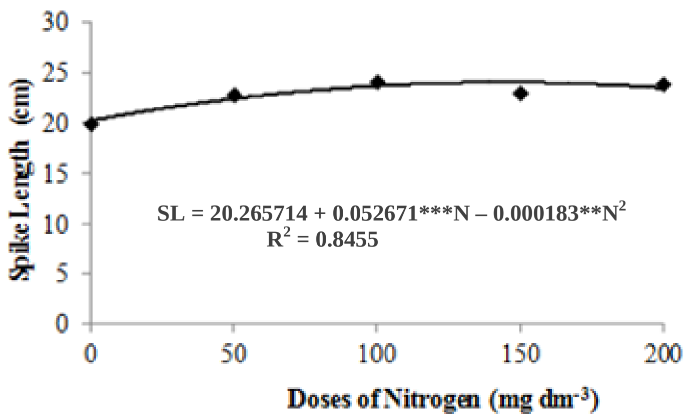

Figure 8. Spike length maize according to doses of nitrogen (mg dm^{-3}). N-Nitrogen.***, ** Significant at 0.1 and 1%, respectively.

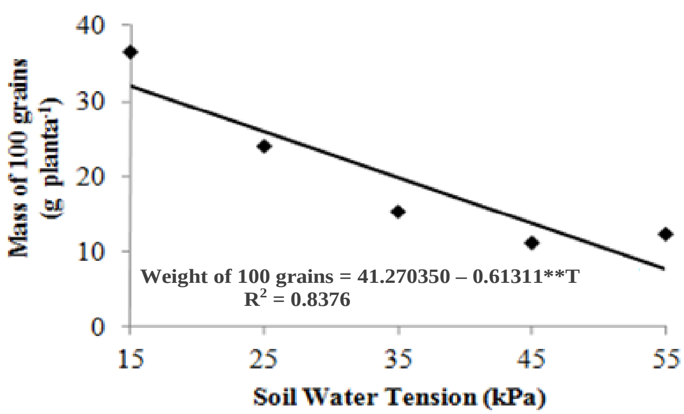

Figure 9. Weight of 100 grains corn according to soil water tension (kPa). T-Tension.** Significant at 1%.

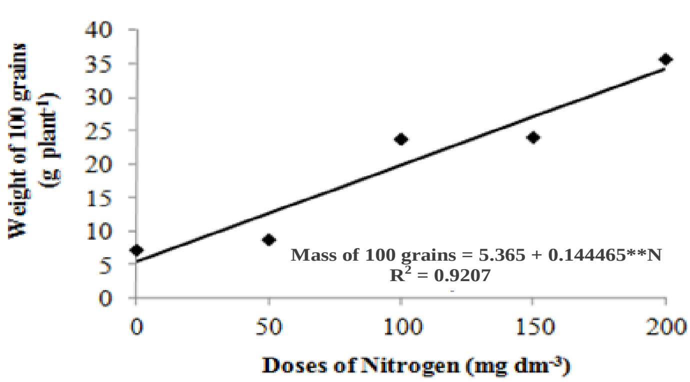

Figure 10. Weight of 100 grains corn according to doses of nitrogen (mg dm^{-3}). N- nitrogen.** Significant at 1%.

Therefore, more frequent irrigations and lower water tension in the soil, combined with the nitrogen rate of 143.91 mg dm^{-3}, performs better for the ear length, which could be indicative of increased productivity. In the weight of 100 grains, there was a significance effect of strains that were isolated from the soil water on the duration irrigation and nitrogen, and the results for the grain weight set the linear regression model. The voltage of the soil water during irrigation influenced the weight of 100 grains, obtaining an R^2 of 83.76% for this variable (Figure 9), for which there was a decrease of 76.46% in the weight of 100 grains when comparing the lowest with the highest measured voltage in the soil water. Therefore, it appears that the lowest pressure (15 kPa) for the duration of irrigation provided the best conditions for obtaining the largest weight production of 100 grains (32.07 g plant^{-1}).

The corn could reduce the grain yield during drought stress during the critical period of the crop, which occurs from tasseling to the top of kernel from 60 to 80 days after emergence (Rossetti and Centurion, 2013). Bergonci et al. (2001) verified a reduction of up to 63.30% when the cultivation of irrigated corn was compared with that of non-irrigated corn, indicating the importance of supplemental irrigation on the yield of corn grain. Fang et al. (2010) obtained the best results for wheat production while conserving water in the soil during the reproductive phase, as well as higher water availability during grain filling. Aydinsakir et al. (2013), analyzing the production and quality of maize subjected to five different water availability, observed that plant height, ear diameter, length, number of grains, weight of 1000 grains and grain protein were reduced with increasing water deficit.

Regarding the doses of nitrogen, the same adjusted linear regression model (Figure 10) increased the production of grain weight at the dose of 200 mg dm^{-3} of nitrogen applied, with an increase of 84.34% in the weight of 100 grains when compared to the treatment without nitrogen fertilizer at the higher dose of the experimental range, indicating the importance of nitrogen fertilizer for increasing the grain yield of maize.

The same linear regression model was obtained by Queiroz et al. (2011) with the application of nitrogen up to 160 kg ha^{-1}, using polymerized urea as a source. The results also corroborate Fernandes et al., (2005), who, when analyzing this variable at the dose of 180 kg ha^{-1}, obtained a 32.91 g weight of 100 grains, this value being close to that in this experiment. Ferreira et al. (2010) obtained quadratic regression models for analyzing the weight of 100 grains at doses 0 to 250 kg ha^{-1} of nitrogen, which verified the greater weight of 100 grains (26.37 g) with a nitrogen dose equivalent to 158 kg ha^{-1}. The application of 200 kg ha^{-1} of nitrogen provided the highest yield, promoting an increase in the grain yield of only 8% compared to 150 kg ha^{-1} and increasing the productivity by 53% compared to the treatment without nitrogen in an experiment conducted by Souza et al. (2011). Araújo et al. (2004) found an increase of 21.84% in grain production when comparing the treatment without nitrogen fertilization to treatment with 240 kg ha^{-1} nitrogen. Carvalho et al. (2001) and Mohammadi et al. (2003) found that the weight of grains is the most important component for predicting corn production. According to Borrás and Otegui (2001), the weight of grains is the component of production that is less affected by changes in management practices and fertilization, which were not observed in the present study. According Genc et al. (2013), both nitrogen and water deficit can be checked by the use of chlorophyll reflectance reader and the data processed in the stove when there are indices.

Conclusions

The increased dry weight of the shoot, root dry weight and ear length were obtained from the interaction of 15 kPa tension with the nitrogen dose of 100 to 150 mg dm^{-3}. The weight of 100 grains had a higher weight when the corn plant was subjected to 15 kPa tension at a nitrogen dose of 200 mg dm^{-3}, with no interaction between the variables.

Conflict of Interest

The authors have not declared any conflict of interest.

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