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Analysis of growth and agronomic characteristics of off-season corn grown insuccession with soybean and submitted to nitrogen doses

Análise de crescimento e características agronômicas do milho safrinha em sucessão com soja e submetido a doses de nitrogênio

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ABSTRACT: Nitrogen (N) fertilizer management strategies for the cultivation of off-season corn grown in succession to soybean can be established by growth analysis. Therefore, the objective was to evaluate the growth and agronomic performance of corn in the off-season due to nitrogen levels in an Oxisol of the Cerrado of the state of Mato Grosso do Sul, Brazil. The experimental design used was in randomized blocks, arranged in a split-plot scheme, with six replications. The plots were formed by five nitrogen doses (0, 40, 80, 120 and 160 kg ha^{-1} of N), and the time of evaluation of the corn development parameters (30, 45, 60 and 75 days after emergency (DAE)) constituted the subplots. The source of N used was urea (45% N), with 30 DAE applied. The cultivar Invictus Viptera 3 of corn was cultivated in the off-season. Plant height, leaf area, number of leaves, dry mass of the plant shoot, physiological indexes of growth analysis were evaluated at 30, 40, 60 and 75 DAE. In the flowering period of corn, after the emission of the female inflorescence, were determined the indirect readings of the leaf chlorophyll, leaf N, height plant, and height of the ear insertion. At the physiological maturity of the grain was evaluated height of ear insertion, ear length, number of rows per ear, number of grains per row and ear diameter, the mass of a thousand grains, and grain yield. The 160 kg ha^{-1} dose of N showed better performance and higher morphophysiological indices for corn off-season in succession to the soybean crop. However, the higher grain yield of corn was obtained with the 126 kg ha^{-1} of N.

Keywords: Chlorophyll. Nitrogen fertilization. Physiological índices. *Zea mays* L.

RESUMO: Estratégias de manejo de fertilizantes nitrogenados (N) para o cultivo de milho safrinha cultivado em sucessão à soja podem ser estabelecidas por análise de crescimento. Portanto, o objetivo foi avaliar o crescimento e o desempenho agronômico do milho safrinha com aplicação de doses de nitrogênio em um Latossolo de Cerrado do Estado de Mato Grosso do Sul, Brasil. O delineamento experimental utilizado foi em blocos casualizados, dispostos em esquema de parcelas subdivididas, com seis repetições. As parcelas foram formadas por cinco doses de nitrogênio (0, 40, 80, 120 e 160 kg ha^{-1} de N) e o tempo de avaliação dos parâmetros de desenvolvimento do milho (30, 45, 60 e 75 dias após a emergência (DAE)) constituíram as subparcelas. A fonte de N utilizada foi a ureia (45% N), com aplicação de 30 DAE. A cultivar utilizada foi a Invictus Viptera 3 de milho safrinha. Altura da planta, área foliar, número de folhas, massa seca da parte aérea, os índices fisiológicos da análise de crescimento foram avaliados aos 30, 40, 60 e 75 DAE. No período de floração do milho, após a emissão da inflorescência feminina, foram determinadas as leituras indiretas da clorofila, N da folha, altura da planta, e altura da inserção de espiga. Na maturação fisiológica do grão, foram avaliados o comprimento da espiga, número de linhas por espiga, número de grãos por linha e diâmetro da espiga, massa de mil grãos e rendimento de grãos. A dose de 160 kg ha^{-1} de N apresentou melhor desempenho e maiores índices morfofisiológicos para milho safrinha em sucessão à safra de soja. Entretanto, o maior rendimento de grãos foi obtido com os 126 kg ha^{-1} de N.

Palavras-chave: Adubação nitrogenada. Clorofila. Índices fisiológicos. *Zea mays* L.

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INTRODUCTION

Corn (*Zea mays* L.) is one of the main cereals grown in the world because of its nutritional qualities. In Brazil, the area occupied by cereals in the 2018/2019 crop year was approximately 17.25 million hectares with cultivation distributed in the first and second corn crop (off-season) (CONAB, 2019). Off-season corn accounted for 71.6% of the area, with an average yield of approximately 5,857 kg ha^{-1}. In Brazil, the state of Mato Grosso do Sul accounts for approximately 11% of the total area cultivated with corn. The largest participation being the cultivation of off-season corn (99.5%), with an average yield of 5,382 kg ha^{-1} (CONAB, 2019). It is mainly grown in succession with soybean (*Glycine max*).

Crop production is dependent on various factors, such as genotype, and biotic and abiotic factors. Of these, the nutrients can be managed relatively easily with emphasis on nitrogen, because this nutrient is absorbed in the largest amount by corn. Therefore, N is considered the primary limiting factor for grain production (MALAVOLTA, 2006; GAVA *et al*., 2010). Nitrogen is fundamental for leaf area establishment and duration, as well as ear formation because both rely on the magnitude of the photo-assimilate production source, i.e., photosynthesis (RAMBO *et al*., 2007). Thus, in off-season corn cultivation, it is typical to use lower nitrogen rates than that adopted during the crop season because there is a low response of the corn planted under these cultivation conditions (ZOZ *et al*., 2019). This indicates that N rates may affect corn plant growth, and consequently, grain yield.

Thus, through the study of plant growth analysis, it is possible to follow the growth patterns of the plants or parts thereof, allowing to infer the contribution of different physiological processes on plant growth. Plant growth analysis is also useful in the study of variation among genetically different plants or under various agronomic conditions (BRAGANÇA *et al*., 2010; LOPES; LIMA, 2015). In summary, the analysis of plant growth is based on photosynthetic production in conjunction with the ontogenetic development of the crop, thereby allowing the elucidation of the method of increased plant dry matter, and its distribution and efficiency under natural or controlled environments (BENINCASA, 2003).

Thus, off-season corn can benefit from the residual fertilization and crop residues that remain on the soil after soybean harvesting, which, during decomposition, provide nutrients (SIMÃO *et al*., 2018). Additionally, the study of growth analysis can aid in establishing nitrogen fertilization management strategies (N) for corn crops grown in succession to soybean with the integration of the no-tillage system (NTS) in the state of Mato Grosso do Sul. Therefore, the objective of this study was to evaluate the growth and agronomic performance of off-season corn plants as a result of nitrogen fertilization in a Red Latosol in the Cerrado of the state of Mato Grosso do Sul.

2 MATERIAL AND METHODS

2.1 LOCATION AND CHARACTERIZATION OF THE EXPERIMENTAL AREA

The study was conducted in an experimental area at the Federal University of Mato Grosso do Sul - UFMS, Chapadão do Sul, MS (18°46 17.9 S, 52°37 25.0 W, and an average altitude of 810 m) in the 2018/2019 crop season. The climate of the region, according to the Köppen classification, is tropical rainy (Aw), with rainy summers and dry winters, with precipitation, annual average temperature, and relative humidity of 1,261 mm, 23.97 °C, and 64.23%, respectively. Precipitation data during the experiments are shown in Figure 1.

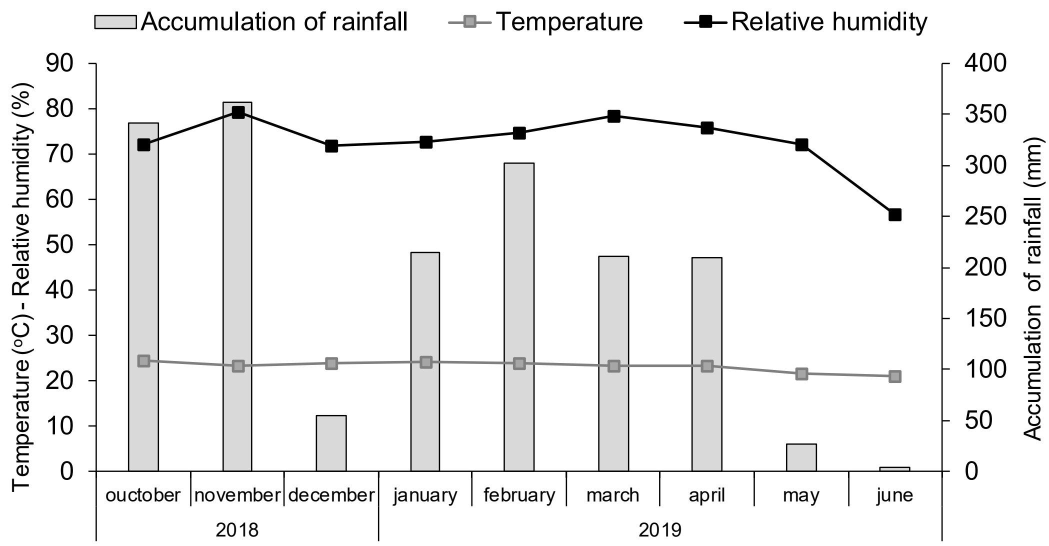

Figure 1. Monthly averages of temperature, relative humidity, and cummulative rainfall occurring in Chapadão do Sul-MS during the 2018/19 corn crop cycle. Source: National Institute of Meteorology (INMET).

The soil of the experimental area was a dystrophic Red Latosol with clay texture. Before starting the experiment, the soil was sampled in the 0–0.20 m layer and the main chemical properties are presented in Table 1.

Table 1. Main chemical properties of the soil used in the experiment

pH	OM	$P_{Mehlich}^{-1}$	H+Al	Al^{3+}	Ca^{2+}	Mg^{2+}	K^+	CTC	V
$CaCl_2$	g dm^{-3}	mg dm^{-3}		--------------------	cmol$_c$ dm^{-3}	----------------------			%
4.3	22.8	12.8	5.7	0.37	2.20	0.40	0.27	8.6	33.5

OM: Organic matter. CTC: Cation exchange capacity at pH 7.0. V: Base saturation.

Soil acidity correction was performed by applying limestone (CaO, 29%; MgO, 20%; relative power of total neutralization [PRNT] 90.1%, power of total neutralization 101.5%). The limestone dose was calculated to increase saturation to 60%, following Sousa's recommendations Sousa and Lobato (2004) applied 0.4 t ha^{-1} of this limestone, considering the PRNT and the non-incorporation of limestone because of the adoption of NTS. Liming was performed 60 days before soybean cultivation. Soybean cultivar Brasmax Bonûs Ipro was sown on October 4, 2018, by mechanically distributing 13 seeds per meter, with spacing of 0.45 m. The base fertilization consisted of 150 kg ha^{-1} of P_2O_5, whose source was MAP (11% ammonia N and 52% P_2O_5). Coverage fertilization was 100 kg ha^{-1} of K_2O, the source of which was potassium chloride at 40 days after emergence (DAE). At 40 DAE, foliar fertilization was applied using Actilase ZM (Zn 50.22 g L^{-1}; S 41.65 g L^{-1}; Mn 30.01 g L^{-1}) and Racine (Mo 108.75) products (g L^{-1}; Co 10.88 g L^{-1}; Total Carbon 123.25 g L^{-1}) at the rates of 1 L ha^{-1} and 120 mL per ha^{-1}, respectively.

2.2 EXPERIMENTAL DESIGN AND TREATMENTS

The experimental design was randomized blocks, with the evaluation made over time in subdivided plots. The treatments consisted of five nitrogen doses (plots): 0, 40, 80, 120, and 160 kg ha^{-1}N. The source of N used was urea (45% N) and was applied 30 DAE. Evaluation occurred at four sampling points for crop growth analysis (subplots): 30, 45, 60, and 75 DAE, with six replications. Each treatment consisted of 10 plants. The Invictus Viptera 3 corn cultivar (single hybrid, early cycle, orange grain color, semi-hard grain texture, glyphosate resistance, and tolerance to ear leaf caterpillars;from the Syngenta Company) was used.

2.3 EXPERIMENTAL IMPLEMENTATION AND PROCEDURES

Pre-harvest soybeanswere desiccated with 2 L ha^{-1} gramoxone. After 5 days, the soybean harvest was performed and the installation of the trials followed the NTS. The corn crop was mechanically sown on February 8, 2019 by means of a fertilizer seeder, with a stem-type furrow mechanism for NTS, at a depth of approximately 3 cm, a spacing of 0.45 cm and 3 cm, and four seeds per meter to reach a final stand of 70,000 to 75,000 plants per hectare. The base fertilization consisted of 200 kg ha^{-1} MAP (11% ammoniacal N and 52% P_2O_5). The corn seeds were treated with 150 g L active ingredient(a.i.) of imidacloprid + 450 g La.i. of thiodicarb. DAE foliar fertilization with Actilase ZM (Zn 50.22 g L^{-1}; S 41.65 g L^{-1}; Mn 30.01 g L^{-1}) was applied at the dose of 1 L ha^{-1}.

Post-emergence weed control (e.g.,volunteer soybean) was conducted with cornat 20 DAE, using the herbicide atrazine at a dose of 2 L ha^{-1} (1,500 g ha^{-1} ai). In the period prior to flowering, the fungicide Epoxiconazole + Pyraclostrobin was applied at a dose of 99.7 + 87.5 g ha^{-1} ai associated with the insecticides Metomil and Imidacloprid + Thiodicarb at the dose of 12.9 and 45 + 135 g ha^{-1} ai, respectively.

2.4 MEASUREMENT OF CHARACTERISTICS

Successive collections of three plants per plot were performed from the 13th DAE at regular intervals of 15 days until 75 DAE. In each collection, the following variables were evaluated: leaf area (LA; cm^2) by the electronic leaf area meter (Li-Cor, L1- 3100®); number of leaves (NL; unit); shoot dry mass (SDM; g): material subjected to forced oven drying at 60 °C for 72 h and weighed on a digital scale (precision 0.001g).

With these data, the physiological indices of growth analysis were calculated, according to Benincasa (2003). For each evaluation, the absolute growth rate (AGR), relative growth rate (RGR), net assimilation rate (NAR), and leaf area ratio (LAR) were determined.

$$AGR \quad \frac{TDM2 - TDM1}{T2 - T1} \qquad \text{(Formula 1)}$$

AGR, in g d^{-1}, was calculated by formula 1, where TDM2 is the total dry mass of the current shoot (g), TDM1 is the total dry mass of initial shoot (g), and T2 - T1 is the time interval between the two collections (15 days). The rate of RGR, in g g^{-1} by d^{-1}, was calculated by formula 2:

$$RGR = \frac{\ln TDM2 - \ln TDM1}{T2 - T1} \qquad \text{(Formula 2)}$$

where ln is the Napierian logarithm.

The NAR was calculated by formula 3:

$$NAR = \frac{TDM2 - TDM1}{T2 - T1} * \frac{\ln LA - \ln LA}{LA2 - LA1} \qquad \text{(Formula 3)}$$

where LA2 and LA1 correspond to the current total leaf area (cm^2) at times T2 and T1, respectively. The LAR, in cm^2 g^{-1}, was calculated by formula 4:

$$LAR = \frac{LA}{TDM} \qquad \text{(Formula 4)}$$

where LA is the current leaf area (cm^2) and TDM is the current total dry mass (g).

During flowering, after female inflorescence emission, indirect readings of chlorophyll leaf content (Falker chlorophyll index, FCI) with an FCI 1030 digital chlorophyll meter (Falker, Porto Alegre, RS) were recorded. The readings were taken from the middle third of the leaves at the base of the ear, using an average of 10 leaves per plot (MALAVOLTA *et al*., 1997). For the leaf diagnosis, the diagnostic area located in the middle third region of the leaves at the base of the ear in 10 plants of each plot was collected. This material was placed in a forced circulation oven at 60 °C for 72 h and then ground in a Willey mill equipped with a 40 mesh sieve. The leaf N determination was performed by the semi-micro Kjeldahl analytical method after digestion in sulfuric acid.

When the culture reached physiological maturity, the ear insertion height (cm), as defined as the distance from the soil surface to the location of the first ear insertion, was determined. The manual harvesting of corn and mechanical threshing with the aid of the winter Steiger Classic® Plot Harvester, to evaluate the components of grain yield and yield (plot useful area), was performed on July 08, 2019, at 120 days after sowing of corn. The ear length, number of rows per ear, number of grains per row, and ear diameter were subsequently determined. Then, the mass of one thousand grains (g) was determined according to the methodology described in Brazil (2009) and grain yield (kg ha^{-1}) was standardized to 13% grain moisture.

2.5 STATISTICAL ANALYSIS

The experimental data were submitted to the verification tests of normality and homogeneity of variance assumptions. Subsequently, the data were submitted to a joint analysis of variance (ANOVA) adopting a statistical model and analysis procedure similar to that presented by Ramalho *et al*. (2012). When significant means were subjected to regression analysis, significant equations according to Student's *t*-test with the highest coefficients of determination (F-test, $p < 0.05$) were adjusted. Regression analysis was performed using SigmaPlot 11.0 software for Windows (Systat Software, Inc., San Jose, CA, USA).

3 RESULTS AND DISCUSSION

In general, the results of plant height, the number of leaves, leaf area, and shoot dry mass in different seasons (Figure 2) increased after nitrogen application at 30 DAE. This is a common occurrence in corn crops, which are highly responsive to nitrogen fertilization even in soybean crop succession. Gava *et al*. (2010) verified higher accumulation of dry matter in the shoots of crop cornafter application of 200 kg ha^{-1} of N, and the largest accumulation of this variable was at 80 DAE. According to Malavolta (2006), corn required a large amount of N for its development. Therefore, higher plant height, leaf number, leaf area, and dry mass accumulation at higher N rates are associated with the physiological processes involved with this nutrient.

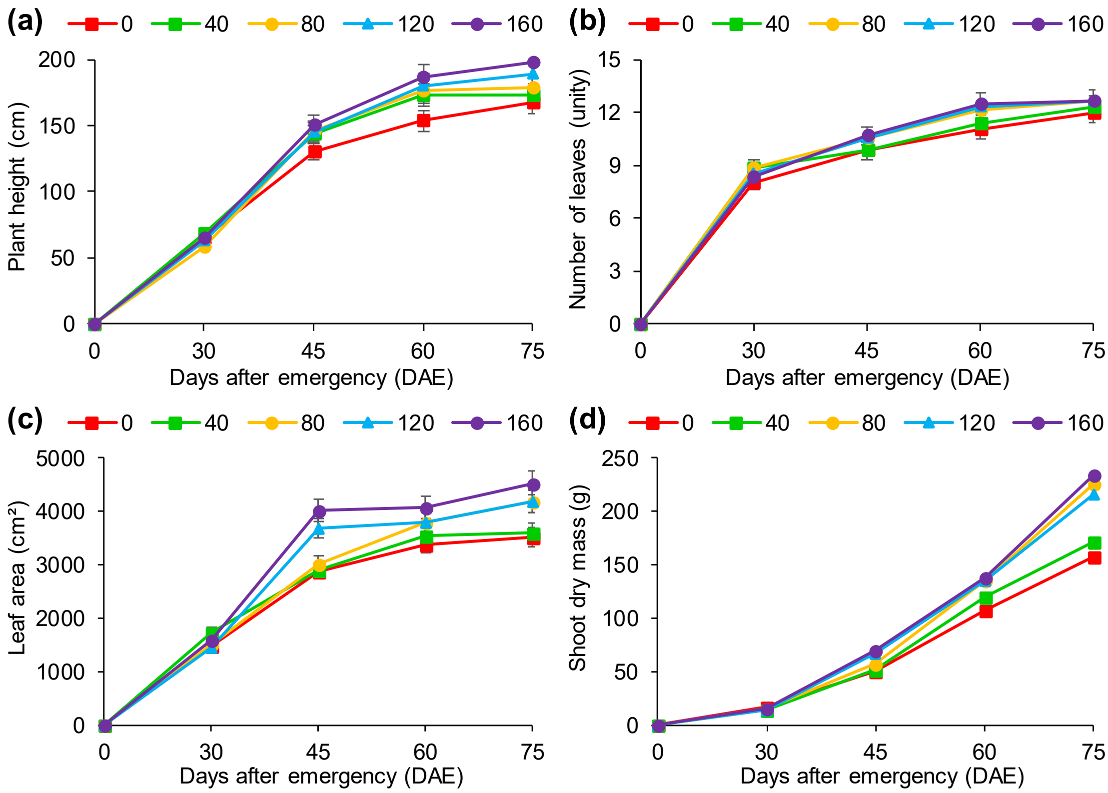

Figure 2. Plant height (a), number of leaves (b), leaf area (c), shoot dry mass (d), obtained in the experiment with nitrogen application rates in off-season corn, with respect to the standard deviation, in Chapadão do Sul, MS, Brazil.

It was also possible to observe that from 30 DAE, the 160 kg ha^{-1} N rate resulted in higher mean values for these variables, and for leaf area at 45 DAE the increase was more extensive. According to Lopes and Lima (2015), high N content induces abundant leaf production and low starch content, whereas the opposite occurs when the N level is low. According to Gava *et al*. (2010), N is part of several physiological processes that occur in the plant, including photosynthesis, respiration, growth, cell differentiation, and genetics. Because N is a constituent of the chlorophyll molecule, it functions in the photosynthetic process, as well as in the formation of amino acids and proteins (DEBAEKE *et al*., 2006). Therefore, with increasing doses of N there was a higher production of chlorophyll molecules, which in turn tended to produce greater leaf area, and consequently, there was an increment of photoassimilates that were distributed to the energy drains (e.g., the development of aerial parts). Thus, growth depends on proteins from photosynthesis and is related to N fertilization.

Absolute growth rate is the variation or increase in growth between two representative plant samples in a population over a given period (BENINCASA, 2003). Figure 3a shows that there was accelerated vegetative growth after 30 DAE in the order of doses 160> 120> 80>40> 0 kg N ha^{-1}, which may be related to the beneficial effects of N, as already discussed. It is noteworthy that for the control and the 40 kg N ha^{-1} dose, the absolute plant growth rate dynamics followed the sigmoidal model, where accumulation was slow at 30 DAE, increasing after this period until 60 DAE, and thereafter exhibiting a marked decrease, mainly because of the stabilization of leaf area, as observed in Figure 2c.

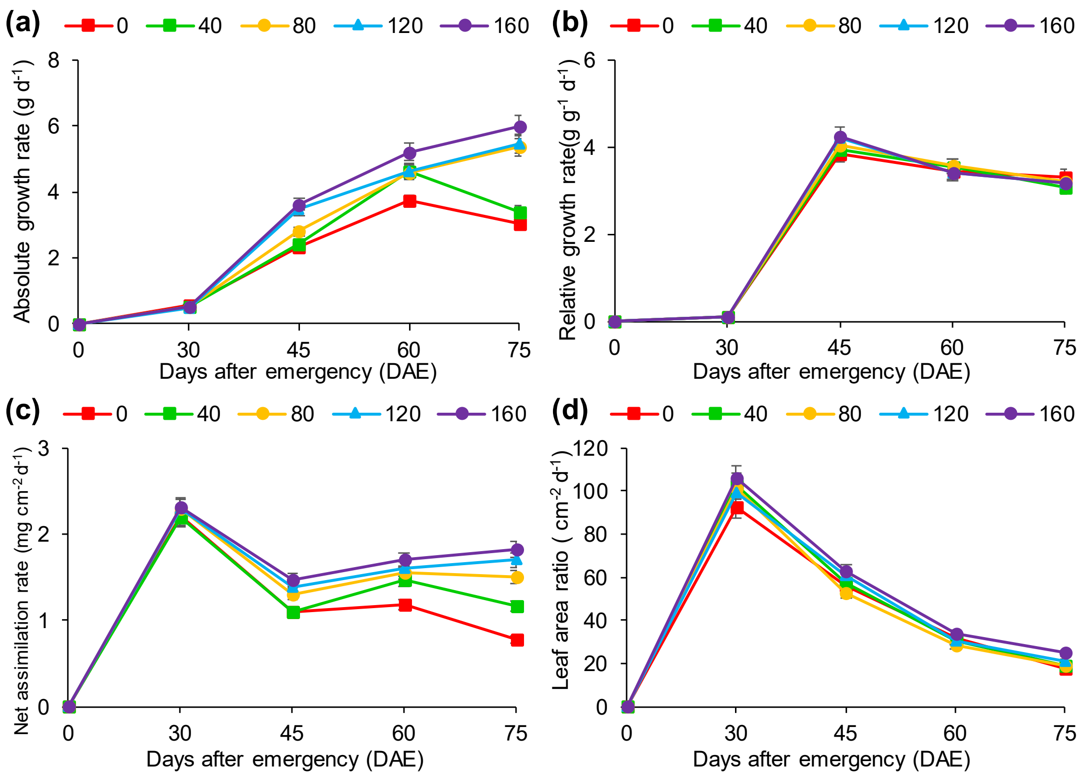

Figure 3. Absolute growth rate (a), relative growth rate (b), net assimilation rate (c), and leaf area ratio (d) obtained in the experiment with nitrogen application rates in off-season corn, with respect to standard deviation, in Chapadão do Sul, MS, Brazil.

Relative growth rate represents the increase in existing dry matter per unit of pre-existing dry matter over a given period (BENINCASA, 2003). The application of 160 kg ha^{-1} N resulted in a higher RGR at 45 DAE (Figure 3b). During this period, the maximum accumulation of RGR was observed at doses 160> 120> 80> 40> 0 kg N ha^{-1}, with the rates of 4.24, 4.22, 4.04, 3.93, and 3.84 g g^{-1} d^{-1}, respectively. Subsequently, at 45 DAE, in general regardless of the N dose, there was a decline up to 75 DAE. Therefore, after nitrogen application (30 DAE), the efficiency of of-f-season corn plants in dry mass conversion was higher at 15 days after application (45 DAE), and this efficiency was proportional to the applied dose. That is, the higher the N dose, the more the dry mass increased. However, all doses of N stabilized after this period. This fact may be related to the formation of new plant tissues in the early phase of growth and development of the crop, where RGR increases as a result of greater leaf emergence and expansion, which is directly related to the photosynthetic capacity of assimilatory tissues (PETTER *et al*., 2016).

The net assimilation rate reflects the photosynthetic efficiency of the leaves (BENINCASA, 2003). It can be seen in Figure 3c that, independent of the dose, the NAR was greater at 30 DAE and decreasing to 45 DAE. According to Pedó *et al*. (2010), NAR reduction was associated with the photosynthetic rate, leaf dimension, duration of the vegetative period, leaf distribution, and photoassimilates. Additionally, at 45 DAE, the maximum accumulation of NAR at doses was at 160> 120> 80> 40> 0 kg N ha^{-1}, with the rates of 1.47, 1.37, 1.30, 1.10, and 1.09 mg cm^{-2} d^{-1}, respectively.

The leaf area ration expresses the leaf area useful for photosynthesis, being the ratio of the leaf area to total dry mass (BENINCASA, 2003). Regardless of dose, LAR also had the largest increase at 30 DAE, and after this period, there was a reduction (Figure 3d). It is possible that this fact is related to the increase in corn growth variables (Figure 2) after N application at 30 DAE. Thus, with N application, there was rapid formation and expansion of leaf area, growth in plant height because of higher photo-assimilate yields, and consequently, self-shading. According to Benincasa (2003), the decline of the LAR occurs because of the increase in interference from the upper leaves on the lower leaves, as the plant grows, creating a tendency of the useful leaf area to decline with the plant developmental stage.

In general, the highest LAR value corresponded to the dose of 160 kg N ha^{-1}, regardless of the evaluated season; a fact proven by higher plant height, leaf number, leaf area, and shoot dry mass. Thus, it was verified that the best growth of off-season corn plants is caused by the increase in the N dose, and the 160 kg ha^{-1} dose was the best.

The results showed that N rates linearly increased with plant height (Figure 4a), chlorophyll (Figure 4b), and leaf N content (Figure 4c). For the insertion height of the first ear, there was no effect of N dose (Figure 4d). Soratto *et al*. (2010) also obtained an increase in plant height of off-season corn grown after soybean with the application of N in coverage.

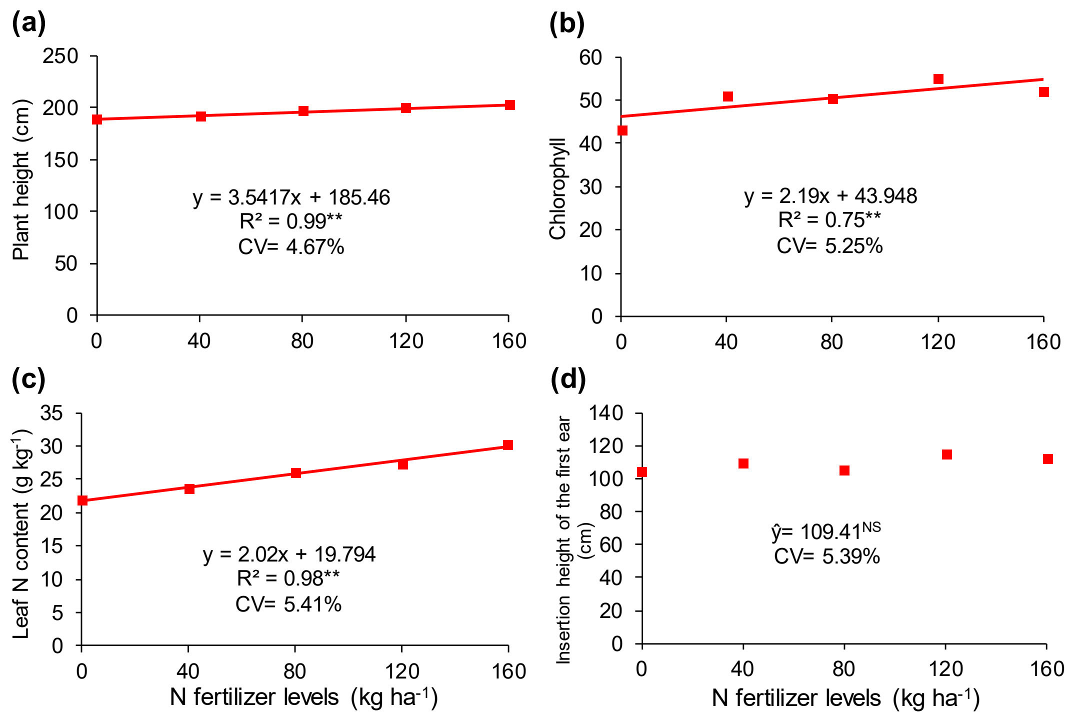

Figure 4. Plant height (a), chlorophyll (b), leaf N content (c), and insertion height of the first ear (d) obtained with nitrogen application rates in off-season corn. Chapadão do Sul, MS, Brazil. CV: coefficient of variation.

N concentrations observed in the present study were below the values described as adequate (27–35 g of N kg^{-1} dry matter) according to Raij (2011). Andrade *et al*. (2014) also found leaf N concentrations below those described as adequate for most N doses studied. The linear increase in the relative chlorophyll content is caused by the participation of N as a constituent of the chlorophyll molecule in the photosynthetic process and the formation of amino acids and proteins (DEBAEKE *et al*., 2006). Thus, the higher vegetative growth of corn plants observed by growth analysis at higher N rates is, in fact, a result of the increase in chlorophyll and leaf N content in plants. Therefore, with increasing doses of N, there was a higher production of chlorophyll molecules, which in turn tended to produce more photoassimilates that were distributed to the energy drains (e.g., area development, and grain formation and filling).

For the cultivar ear length (Figure 5a) and one thousand grain mass (Figure 5e) the results showed that the N rates increased linearly; however, for row number per ear (b), number of grains per row (c), and ear diameter (d) there was no significant effect of N fertilization. Castañon *et al*. (2014) and Zoz *et al*. (2019) also obtained an increase in the mass of one thousand grains of off-season corn cultivated after soybean with the application of N in coverage. As N directly participates in protein and carbohydrate synthesis, an increase in the mass of one thousand grains should be expected (ANDRADE *et al*., 2014).

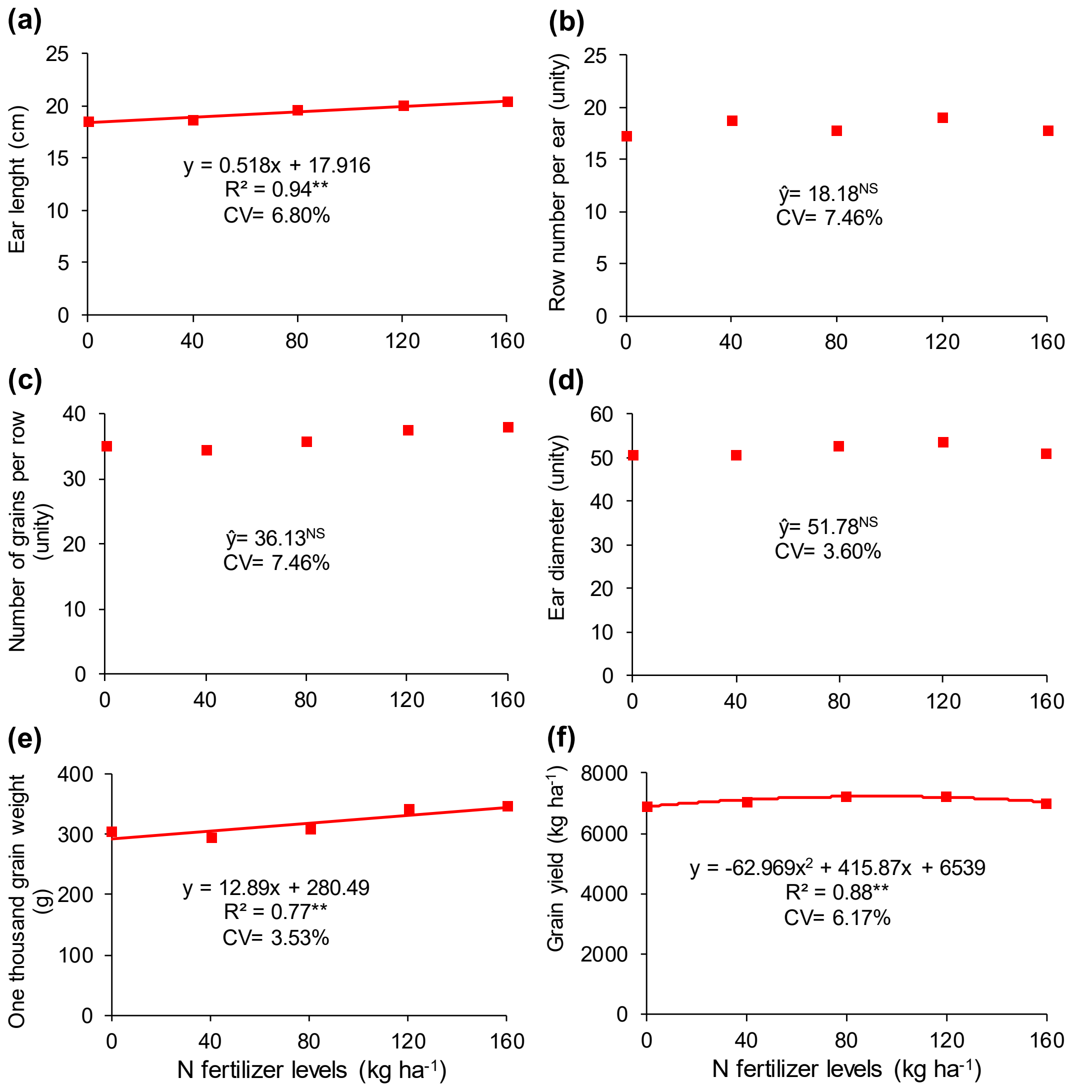

Figure 5. Ear length (a), row number per ear (b), number of grains per row (c), ear diameter (d), one thousand grain weight (e), and grain yield (f), obtained in the test with nitrogen application rates on off-season corn. Chapadão do Sul, MS, Brazil. CV: coefficient of variation.

For grain yield, the results fit the quadratic regression model (Figure 5f). The maximum grain yield of 7,226 kg ha^{-1} occurred with the dose of 126 kg ha^{-1} of N. Sorato *et al.* (2010) also found an increase in the yield of off-season corn with the supply of N, and obtained an increase in corn yield up to 120 kg ha^{-1} of N. Therefore, nitrogen,in addition to promoting improvement in plant growth of off-season corn (Figures 2 and 3), is reflected in the yield of corn grains.

It can be inferred that the nitrogen supply favors initial growth and production potential of the off-season corn crop in succession to the soybean crop. This fact is highly relevant because, from an economic point of view, grain production is more important than total dry mass. Additionally, in this study, the beneficial effect of N fertilization was observed soon after the application of N (vegetative phase) until grain production. Collectively, our findings demonstrate the importance of N fertilization in off-season corn, even in soybean succession cultivation.

4 CONCLUSION

The rate of 160 kg ha^{-1} of N presented better performance and higher morphophysiological indices for corn crop grown in succession to the soybean crop; however, the dose of 126 kg ha^{-1} of N resulted in higher grain yield.

5 ACKNOWLEDGMENTS

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