Scientific Electronic Archives
Issue ID: Sci. Elec. Arch. Vol. 12 (4)
August 2019
Article link
http://www.seasinop.com.br/revista/index.php?journal=SEA&page=article&op=view&path%5B%5D=851&path%5B%5D=pdf
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SCIENTIFIC ELECTRONIC ARCHIVES
ISSN 2316-9281

Nitrogen released from soybean crop in the performance of off season maize

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Abstract. The objective of this study was to evaluate the effect of Nitrogen (N), released from the soybean straw, on the variables of vegetative growth and grain yield of off season maize. The maize hybrid 2B688 PW® was sowed on 02/26/2014, on the straw of a previous soybean experiment, seeded in October 2013, at the experimental area of the UFMT, campus Sinop-MT. The experimental design was randomized block with four replicates and a 2x8 factorial scheme. The first factor was the soybean cultivars (TMG 133 RR and TMG 1188 RR) and the second factor was the management of the soybean crop with different forms and doses of inoculant, plus a control and a treatment with the application of 200 kg of mineral N. The vegetative growth variables and grain yield were assessed. The variables of vegetative growth were not altered by the management of inoculation/fertilization with mineral N or the soybean cultivar used as the previous crop. The grain yield was affected by the soybean cultivar and the interaction of cultivar and treatments carried out on the soybean previous cultivated. The grain yield was higher with the use of the TMG 1188 RR cultivar and inoculation in the seed by peat inoculant.
Key words: *Zea mays*, Chlorophyll. Demand of nitrogen in maize. Vegetative growth. Grain yield.

Introduction

Maize (*Zea mays* L.) is one of the most important cereals grown and consumed in the world, due to its yield potential, nutritional value and uses, both in human and animal feed. In Brazil, in the 2016/2017 harvest, about 96 million tons of maize were produced, behind the United States and China, which produced approximately 384.8 and 219.6 million tons, respectively. In Brazil, it is estimated that in the off season crop of maize in 2017, around 61 million tons were produced, almost 60% of the total in the country. The State of Mato Grosso stands out in the off season crop ("safrinha") in succession mainly after the cultivation of the early soybean. This is the state with the highest increase in production of off season maize crop, which will be 64% higher than in the 2015/16 crop, from 15 million tons to 24.7 million in the 2016/17 harvest, a fact justified by the cultivated area and yields achieved. Mato Grosso is responsible for almost 40.5% of maize production in the off season crop in Brazil (CONAB, 2017).

Due to its physiological characteristics, maize crop has a high yield potential, reaching up to 16,000 kg ha^{-1}, recorded in maize yield surveys in Brazil (EMBRAPA, 2013). However, in general the cultural management of maize still needs to be improved in order to obtain an increase in crop yield and profitability. Off season crop, after soybean, allows the intensive use of the soil, labor, machinery, promotes the rotation / succession of legumes with grasses, keeping straw in the soil, with pest and disease reductions (Chagas et al., 2007), maintenance / increase of soil organic matter, besides the release of nutrients from straw, mainly N.

Maize is high demanding on nutrients, especially N (Bastos et al., 2008) and the use of no-tillage systems should be considered in N fertilization. In Brazil the use of cover crops and crop rotation aim the sustainability of this system. It is necessary to consider the utilization of the residual N, from the soybean straw, in the N fertilization of the maize in the off season crop, cultivated in succession, through the decomposition of the vegetal residues.

The maintenance of vegetal residues of soybean, on the soil, to harness the off season crop is an important variable in the nutrients cycling. However, depending on the management given to those residues, leaving them to surface or incorporating them in the soil, and depending on the climatic conditions of the region, will result in different decomposition rates (Torres et al., 2005). The establishment of cover crops for the formation and maintenance of cultural residues on the soil surface, especially in the Cerrado regions, has encountered some obstacles, since climatic conditions in these regions favor the decomposition of plant residues fastly. The time of crop decomposition of cover crops may vary from 42 days after desiccation management (Torres et al., 2005) up to 63 days (Moraes, 2001). This decomposition is mainly controlled by the C / N ratio, lignin content, which will define the size of the fragments and the action of the climate, mainly air temperature and precipitation (Torres et al., 2005).

Among the nutrients present in the soybean plant that can be utilized by maize, we can mention the N, which is required in greater quantity by both. The maize crop responds to high doses of this nutrient, with the recommendation of the use of cover crops, such as crotalaria and crotalaria + millet as predecessors associated with the application of 120 kg ha^{-1} of N in cover, which increases production costs (Kappes et al., 2013). Thus, in the decision of N fertilization should be considered: cropping system (no-tillage), sowing season (off season crop), crop rotation and N sources, among others, emphasizing that recommendations of N should be specific and not generalized (Chagas et al., 2007).

The objective of this study was to verify the effect of N released from early soybean straw on the vegetative growth and grain yield of off season maize, in succession.

Methods

The experiment was conducted from February to June of 2014 in the second crop at the experimental area of the Federal University of Mato Grosso (UFMT), located in the Sinop-MT city, 11°86'55'' S of latitude, 55°48'45'' W of longitude and 384 m of altitude, whose topography of the place is flat. The climate of the region, according to the Koppen classification, is of type Am, with average annual rainfall of 2000 mm per year, average annual temperature of 26°C and air average relative humidity of 66%. The meteorological data, during the period of conduction of the experiment, were obtained from the meteorological station of the UFMT Campus Sinop, distant about 150m from the experiment site (Figure 1).

The experimental area was in the first year of implementation of the no-till system and the previous year's crop was conventional tillage rice. In the agricultural year 2012/2013 the previous crop was soybean and maize was grown as off season crop next. The soil of the experimental area is classified as Distrofic Red Latosol (Santos et al., 2013). The results of the chemical analysis of the soil before the sowing of soybean were: pH in H2O (5.0), Organic matter (21.84 g kg^{-1}); (2 mg dm^{-3}), K (10 mg dm^{-3}) obtained with Mehlich-1 extractor with 0.01 mol / L KCl extract, Ca (39 mmolc dm-3), Mg (7 mmol dm^{-3})), V (14.78%). Micronutrients expressed as mg dm^{-3} were: B (0.30) extractor CaCl2, Cu (0.61), Fe (150.09), Mn (2.96) and Zn (0.43) with extractor Mehlich-1. With the physical analysis of the soil the contents of 311, 179 and 510 g kg^{-1} of sand, silt and clay were found, respectively.

The experimental design was randomized block design with four replicates. The experimental scheme was a factorial 2x8, and the treatments were still carried out in the previous crop, soybean. After the soybean harvest, the experiment was sown in all plots with maize hybrid 2B688 PW. The first factor, with eight levels, consisted of: absolute control (without N and application of inoculant) in the soybean; standard control with 200 kg ha^{-1} of N (200 kg N); 400 ml of liquid inoculant in the seed (400 IS); 400 mL of peat inoculant in the seed (400 ITS); 400 mL liquid inoculant in the groove (400 LSU); 100 mL inoculant liquid seed (100 LS); 100 mL liquid groove inoculant (100 LSU); 100 mL peat inoculant in the seed (100 TUS). The second factor was the two soybean cultivars of extensive regional use in soils of new areas in Mato Grosso: TMG-1188RR and TMG 133 RR (Pereira et al., 2016).

In the same experimental area of the previous experiment with soybean, the 2B688 PW® maize hybrid of Dow Agrosciences was used as the second crop. The plots consisted of five five-meter rows, spaced 0.45 m between rows, totaling 12.5 m² and a 6 m² plot (central rows), eliminating half a meter at each end and the two rows edges. The inoculants used had the minimum concentration of 5.0 x 10^{109} and 7.2 x 10^{109} cells per gram of inoculant, peat and liquid, respectively. *Bradyrhizobium japonicum* on peat substrate was diluted 1: 1 (water / inoculant). The inoculation was performed manually in polyethylene bags until there was perfect and homogeneous coverage of the seeds by the treatments (Pereira et al., 2016).

The soil was corrected with lime with 10% MgO and 46% CaO in its composition and incorporated before the soybean experiment in order to raise the base saturation to 60%. Seeding of second crop occurred on February 26, 2014, shortly after the experiment with soybean and was performed manually, with double recommended seeds, suffering, after the emergency, a thinning, with the aid of a pair of scissors, for the population reaches 60,000 plants ha^{-1}. Fertilization was calculated in order to provide adequate amounts of N, P and K, based on the expectation of obtaining good grain yield (Ribeiro et al., 1999). As fertilization, it should be considered that it was carried out in two stages, first in the soybean crop, where 100 kg ha^{-1} of P_2O_5 and 90 kg ha^{-1} of K_2O were applied. Also in the soybean crop, micronutrient application was carried out, since it is known that the micronutrients in soybean are the limiting nutrients for yield, especially B (Santos, 2008). A foliar fertilization of 2 kg ha^{-1} of Zn and B was carried out near the flowering of the soybean, the sources being zinc sulfate and boric acid. In V3, cobalt and molybdenum-based products were applied in the dose of 5 g of Co and 42 g of Mo per ha, as recommended by Almeida (2011) to increase soybean nodulation and yield. Furthermore, in the flowering time, sulfur was applied at a dose of 40 kg ha^{-1}.

In the maize sowing, the application of 500 kg ha^{-1} of 04-14-08 in the sowing line was carried out. In the cover, about 15 days after emergence (DAE) in V4, 20 kg ha^{-1} of N from urea source was applied, totaling 40 kg ha^{-1}. At 15 DAE was also applied 40 kg ha^{-1} of S in the elemental form, and it should be noted that in this period the precipitations were still intense, even occurring a rainfall of more than 80 mm the other day after the cover fertilization (Figure 1).

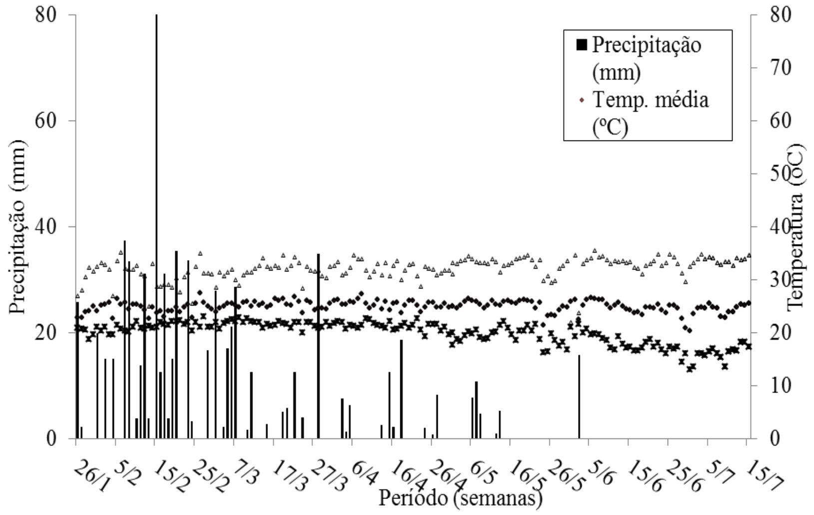

Figure 1. Precipitation (mm) and average temperature (ºC) during the period from January 26 to July 15, 2014. Agricultural year 2013/2014. UFMT, Sinop - MT.

Sprays of herbicides, insecticides and fungicides, when needed, were done with a manual costal sprayer. On March 15, 2014, at the V3 development stage, 2 L ha^{-1} of glyphosate and 2L ha^{-1} of atrazine were applied to control weeds and soybean plants. On March 22, 2014, the application of azoxystrobin-based fungicide 200 g L^{-1} + cyproconazole 80 g L^{-1} at the dose of 300 mL ha^{-1} and insecticide with 250 g L^{-1} of zeta-cypermethrin at the dose of 160 mL ha^{-1} of the product. The chlorophyll content, related to the leaf green color content, was determined on April 8, 2014 at 65 days post emergence when the plants were in the R1 flowering stage. For this evaluation three values were collected on the leaf below and opposite the main ear of four plants per plot, (Argenta et al., 2001; Amaral et al., 2005).

The vegetative development was evaluated in four plants of the plot, evaluating the stem diameter, plant height, leaf area index, number of leaves per plant and ear height, at the R1 developmental stage. Plant height and ear insertion height were obtained with the aid of a set, measuring from the soil to the beginning of the tassel or up to the height of the main ear, respectively. Then, these plants were cut close to the ground and the aerial part was taken to the Laboratory of Feeding and Animal Nutrition of the UFMT, where the number of leaves was obtained, the stem diameter was determined just above the second internode with the aid of a digital caliper and the leaf area with the aid of a Li-Cor leaf area integrator model LI-3010. On July 18, the maize crop was manually harvested for yield determination.

Harvesting was performed by manual threshing of all ears of each plot with the aid of a manual corn thresher DM-21 BOTINI®. The humidity was determined by standard oven method with forced air circulation at 105 ± 3ºC for 24 h in three replications, according to the recommendations described in the Seed Analysis Rules (BRASIL, 2009). After the threshing and measuring grain moisture, the yield in kg ha^{-1} was determined, with water content corrected to 130 g kg^{-1}.

Tests of addictively of the model, normality of errors and homogeneity of variances were performed. The data obtained were subjected to analysis of variance at 5% of probability level using the Sisvar® software (Ferreira, 2011), since no restriction to the assumptions was verified. Means were grouped by the Scott-Knott test at 5% probability level.

Results and discussions

The use of inoculants with *Bradyrhizobium japonicum*, soybean cultivars TMG 133 RR and TMG 1188 RR, as well as the interaction between these factors did not interfere with the vegetative growth of the maize hybrid 2B688 PW (stem diameter, plant height, leaf area and ear insertion height) and the leaf chlorophyll index. In relation to grain yield, this was significantly altered by the interaction between inoculant application with *Bradyrhizobium japonicum* and soybean cultivars TMG 133 RR and TMG 1188 RR (Table 1).

Table 1. Summary of variance analysis for the variables: stem diameter (SD); chlorophyll (CHLOR); leaf area index (LAI); plant height (PH) and ear insertion height (EIH) and grain yield (PROD) of 2B688 PW maize hybrid, seeded under soybean cultivars TMG 133 RR and TMG 1188 RR inoculated at different doses and fertilization forms nitrogen, UFMT, Sinop - MT.

Sources of Variation:	GL	Mean Squares					
		SD (mm)	CHLOR	LAI (m^2)	PH (m)	EIH (m)	YIELD (kg ha^{-1})
Blocks	3	0.26	68.13	0.33	0.06	0.05	1991877.80
Treatments (T)	7	0.26	330.48	0.33	0.22	011	665645.98
Cultivars (C)	1	0.02	35.40	0.04	0.00	0.03	881955.76**
T x C	7	0.15	251.96	0.20	0.39	0.08	1007788.36**
Error	45	1.57	1952.62	1.34	1.20	0.05	2534266.95
General Average		34.54	55.32	1.124	2.388	0.896	6012.05
CV(%)		5.40	11.91	15.33	6.83	11.79	6.95

** significant at 1% probability by F test, respectively; GL - Degree of freedom; CV - Coefficient of variation

Table 2. Average grain yield of the 2B688 PW maize hybrid, seeded after soybean varieties TMG 133 RR and TMG 1188 RR, as a function of different doses and forms of inoculation and nitrogen fertilization and treatments of the previous soybean crop *. UFMT, Sinop-MT.

Treatments:	TMG 133 RR	TMG 1188 RR
Control 1	5896.25 Aa	5890.00 Aa
Control 2 (200 Kg N)	6000.00 Aa	5921.25 Aa
400 IS	5997.00 Aa	6032.50 Aa
400 ITS	5802.50 Aa	6214.50 Aa
400 LS	5550.25 Ba	6136.50 Aa
100 LS	6097.50 Aa	6188.14 Aa
100 LSU	5975.50 Aa	6225.50 Aa
100 TSU	5838.25 Ba	6427.50 Ab

* Control 1 (without application of inoculant and without N); Control 2 with 200 kg of N ha^{-1} (200 kg N); 400 mL inoculant in seed (400 IS); 400 mL of peat inoculant in the seed (400 ITS); 400 mL liquid inoculant in the groove (400 LSU); 100 mL inoculant liquid seed (100 LS); 100 mL liquid groove inoculant (100 LSU); 100 mL peat inoculant in the seed (100 TSU)

** The averages followed by the same lowercase letters in the column and upper case in the row belong to the same cluster by the Scott-Knott test at 5% probability.

It was verified that treatments based on peat inoculant, independent of the dose or application form in the soybean, did not alter the maize growth variables such as stem diameter, chlorophyll index, plant height and height of first ear relative to the liquid inoculant in the seed or sowing groove. Probably the Bradyrhizobium bacterium applied through peat in areas of first year has greater efficiency in the infection and nodulation of the soybean crop. In addition, the peat keeps the rhizobia active for longer in the soil.

Brandelero et al. (2009) verified that the peat inoculant in the seed in areas of first year of cultivation present three times greater results in the fixation of bacteria in the nodule by soybean plant in relation to the control, with greater rooting and higher index of chlorophyll in soybean leaves favoring the fixation of N and greater contribution of residual N. This confirms that, when well inoculated, soybean has higher nodulation and fixes the atmospheric Nitrogen (N2) efficiently, which generates higher residual N gain for the later crop in succession, in the case of maize.

The residual effect of N from the summer crop, in that case of soybean, was of low magnitude and did not add enough N to change the characteristics (Cantarella & Duarte, 2004). In the second crop, the results suggest that investment should be done in the fertilization of maize sowing, in detriment of the low amount of residual N obtained from the fertilization of the summer crop. N fertilization should be carried out both in sowing fertilization and in cover, because in the second crop, the maize yield potential is lower, the crop cycle is generally higher and the risks may increase due to the lower rainfall, (Sichocki et al., 2014).

In the evaluation of the grain yield, the interaction between the soybean cultivars and the treatments carried out on the soybean previous cultivated were verified. After the split of the interaction, it was verified that the treatments in the soybean interfered in the yield of the maize, only when the soybean variety TMG 1188 RR was cultivated and there was no difference in the maize with the cultivar TMG 133 RR (Table 2).

It is verified for the grain yield that the only treatment that reached a significant greater yield was 100 mL peat inoculant in the seed (100 TSU) in the cultivar TMG 1188 RR, being a difference of 537 kg ha^{-1} in relation to the control. In general, Pereira et al. (2016) also verified differences in the yield of soybeans in the summer crop, being the cultivar TMG 1188 RR more productive than TMG 133 RR, which was attributed by the authors to the longer cycle of this cultivar.

When inoculating seeds of nine soybean cultivars with *Bradyrhizobium japonicum*, with strains SEMIA 587 and SEMIA 5019, Brandelero et al. (2009) found that nodulation has a close relationship with final yield, due to the high N demand for grain production. Vieira Neto et al. (2008) reached the same conclusion, and found that treatments that received the inoculant in the sowing groove, at the recommended dose, also had the highest number of nodules formed, and there was a direct relationship between the soybean yield and the amount of residual N for the later crop.

The grain yield varied from 6427.50 to 5550.25 kg ha^{-1}, with a mean of 6,012 kg ha^{-1}, a grain yield value of maize slightly above the state average of 5975 kg ha^{-1} (CONAB, 2017). These values can be attributed to good management practices, both in agriculture and soil, including liming and fertilization. Results from research in the country show that off season maize has a yield potential greater than 6000 kg ha^{-1} grown or not in succession to soybean (Duarte, 2013; Sichocki et al., 2014; Silva et al., 2015; Fiorini et al. al. 2015).

Regarding nutrient utilization, mainly N for second crop maize, further studies are still needed, especially with more soybean cultivars, in more locations of Mato Grosso state, under different climatic conditions and soil types, in order to achieve definite results.

Conclusions

Maize cultivated in the second crop, after soybean cultivars TMG 133 RR and TMG 1188 RR submitted to N fertilization or application of inoculants with *Bradyrhizobium japonicum* does not present an increase in its vegetative growth. The off season maize increases its yield when the predecessor crop is soybean cultivar TMG 1188 RR with the application of rhizobium with *Bradyrhizobium japonicum* via seed in peat form.

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