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Productivity of corn and beans as affected by season and source of nitrogen

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Abstract

Enhanced-efficiency fertilizers, which provide a reduction in nitrogen (N) losses, can be a viable alternative for the anticipation of topdressing for the moment of sowing, besides reducing operations for the rural producer. This study aimed to determine the effect of the period of application of enhanced-efficiency nitrogen fertilizers on the grain yield of corn and common bean in the Cerrado region in the direct seeding system. The experiment was carried out during two crop seasons (2019/2020 and 2020/2021), under field conditions. The completely randomized blocks experimental design was used, being arranged in a 2x4+1 factorial, with four replicates. Treatments consisted of the combination of the following two periods of nitrogen application: at sowing and recommended (four open leaves of corn and third trefoil in beans); and of the four following types of nitrogen fertilizers: 1. urea + NBPT + Zeolite; 2. urea + B + Cu + Zeolite; 3. Super N; and 4. Urea. Additionally, a control treatment (without N) was included. Nitrogen values for application in the treatments were adjusted so that 150 kg ha^{-1} N was applied to the corn, cultivated in summer, and 90 kg ha^{-1} N was applied to the common bean, cultivated in winter. It was concluded that nitrogen sources and period of nitrogen application did not affect corn grain yield, yield components, and common bean grain yield. The application of nitrogen in corn or common bean provided significant increases in crop grain yield.

Keywords: nitrogen fertilization; nitrogen fertilizer; *Phaseolus vulgaris*; no-tillage system; *Zea mays*.

Produtividade de milho e feijão afetada pela época e fonte de nitrogênio

Resumo

Os fertilizantes com eficiência aumentada, que proporcionam redução das perdas de nitrogênio (N), podem ser alternativas viáveis para proporcionar a antecipação da adubação de cobertura para a semeadura e reduzir operações para o produtor rural. O objetivo do trabalho foi determinar o efeito da época de aplicação de fertilizantes nitrogenados de eficiência aumentada nas produtividades de grãos do milho e feijão-comum na região do Cerrado no sistema de semeadura direta. O experimento foi desenvolvido durante duas safras agrícolas, 2019/2020 e 2020/2021, em condições de campo. O delineamento experimental foi em blocos completos casualizados, no esquema fatorial 2x4+1, com quatro repetições. Os tratamentos constaram da combinação de duas épocas de aplicação de nitrogênio, semeadura e recomendada (quarta folhas aberta no milho e terceiro trifólio no feijão) com quatro tipos de fertilizantes nitrogenados (1. ureia + NBPT + Zeólita), 2. (ureia + B + Cu + Zeólita), 3. Super N e 4. Ureia). Adicionalmente foi incluído um tratamento controle (sem N). No milho, cultivado no verão, aplicou-se 150 kg ha^{-1} de N e no feijão-comum, cultivado no inverno, aplicou-se 90 kg ha^{-1} de N. Concluiu-se que as fontes nitrogenadas e a época de aplicação do nitrogênio não afetaram a produtividade de grãos da cultura do milho, os componentes de produção e a produtividade de grãos do feijão-comum. A aplicação de nitrogênio no milho ou no feijão-comum proporcionou incrementos significativos na produtividade de grãos das culturas.

Palavras-chave: adubação nitrogenada; fertilizante nitrogenado; *Phaseolus vulgaris*; sistema plantio direto; *Zea mays*.

Introduction

Nitrogen (N) is one of the most dynamic nutrients in the soil, being more susceptible to losses (CARVALHO et al., 2016; NASCENTE et al., 2014; MORO et al., 2013), and the low efficiency of the agronomic use of this nutrient, which is observed in most agricultural systems, is partially a result of volatilization and losses associated with the nitrification of N, such as those caused by leaching and denitrification of $N\text{-}NO_3^-$ (FAGERIA, 2014). The efficiency of the processes of N use and loss in the soil-plant system has both economic and environmental consequences, especially when N-oxides are emitted into the atmosphere. Nitrous oxide (N_2O) has been receiving increasing attention due to its contribution to the greenhouse effect and depletion of the ozone layer (CHIEN, et al., 2009). Thus, the development of technologies that increase nitrogen use efficiency can help to reduce losses, the contamination of the atmosphere (with nitrous oxide), and ammonia volatilization.

In Brazil, the annual consumption of N fertilizers in 2018 was 9.2 million tons. Out of this total, 61% was urea (DUARTE et al., 2018), which is the most used nitrogen fertilizer. This fertilizer has the following advantages: lower price per unit of N; high concentration of N, which reduces the cost of transport and application; high solubility; less corrosiveness; and compatibility with a large number of other fertilizers (FARIA et al., 2013, 2014). However, the main disadvantage of urea is the high possibility of NH_3 volatilization loss. When applied to the soil, urea undergoes enzymatic hydrolysis, releasing ammonia (FAGERIA, 2014). According to Civardi et al. (2011), the losses of ammonia volatilization by the application of urea on the soil surface without incorporation can reach 78%.

In this context, the use by farmers of enhanced-efficiency fertilizers has been increasing. These fertilizers aim to enhance nutrient use efficiency by reducing losses through leaching, volatilization, and nitrous oxide emission, or by increasing plant uptake through its gradual supply according to plant demand (FRASER et al., 2013; ALMEIDA et al., 2017). Among technologies available to increase N use efficiency, slow- and controlled-release fertilizers stand out (GUELFI, 2017). Thus, several modifications have been made to urea-containing fertilizers to reduce volatilization losses and increase their use efficiency. These modifications include the addition of acid products (BREMNER; DOUGLAS, 1971) and the production of fertilizers with controlled solubility through resins, polymers, and elemental sulfur coatings (GOULD et al., 1986; FANSURI et al., 2008; CIVARDI et al., 2011; MORO et al., 2013).

Examples of products that can be used to reduce N loss in agricultural systems are polymer-coated urea (coated urea). These products provide reasonable/good control over the N release rate (TRENKEL, 2010), such as N-(n-Butyl) triophosphoric triamide (NBPT), which is one of the most studied urease inhibitors (KISS; SIMIHAIAN, 2002). Organophosphate compounds are structural analogues of urea and are some of the most effective inhibitors of urease activity, blocking the active site of the enzyme (WATSON et al., 1998; TRENKEL, 2010).

Another product used is urea coated with boric acid and copper sulfate, which provides positive effects in reducing N volatilization losses (FANSURI et al., 2008). The acidifying effect, the similar structural characteristics of boric acid with urea, and the defensive effect of B and Cu from soil microorganisms can shift part of the urease activity to boric acid, consequently decreasing N volatilization losses (FARIA et al., 2013).

There are still few studies in the literature that demonstrate the effects of the application of fertilizers containing urea coated with slow-release polymer, urease inhibitor or micronutrients for agricultural systems in the Cerrado region. The hypothesis of this paper is that the use of enhanced-efficiency nitrogen fertilizers provides lower nitrogen losses, allowing for their application at sowing.

This paper aimed to determine the effect of the period of application of enhanced-efficiency nitrogen fertilizers in the production components and in the grain yield of corn and common bean in no-tillage system in the Cerrado region.

Material and Methods

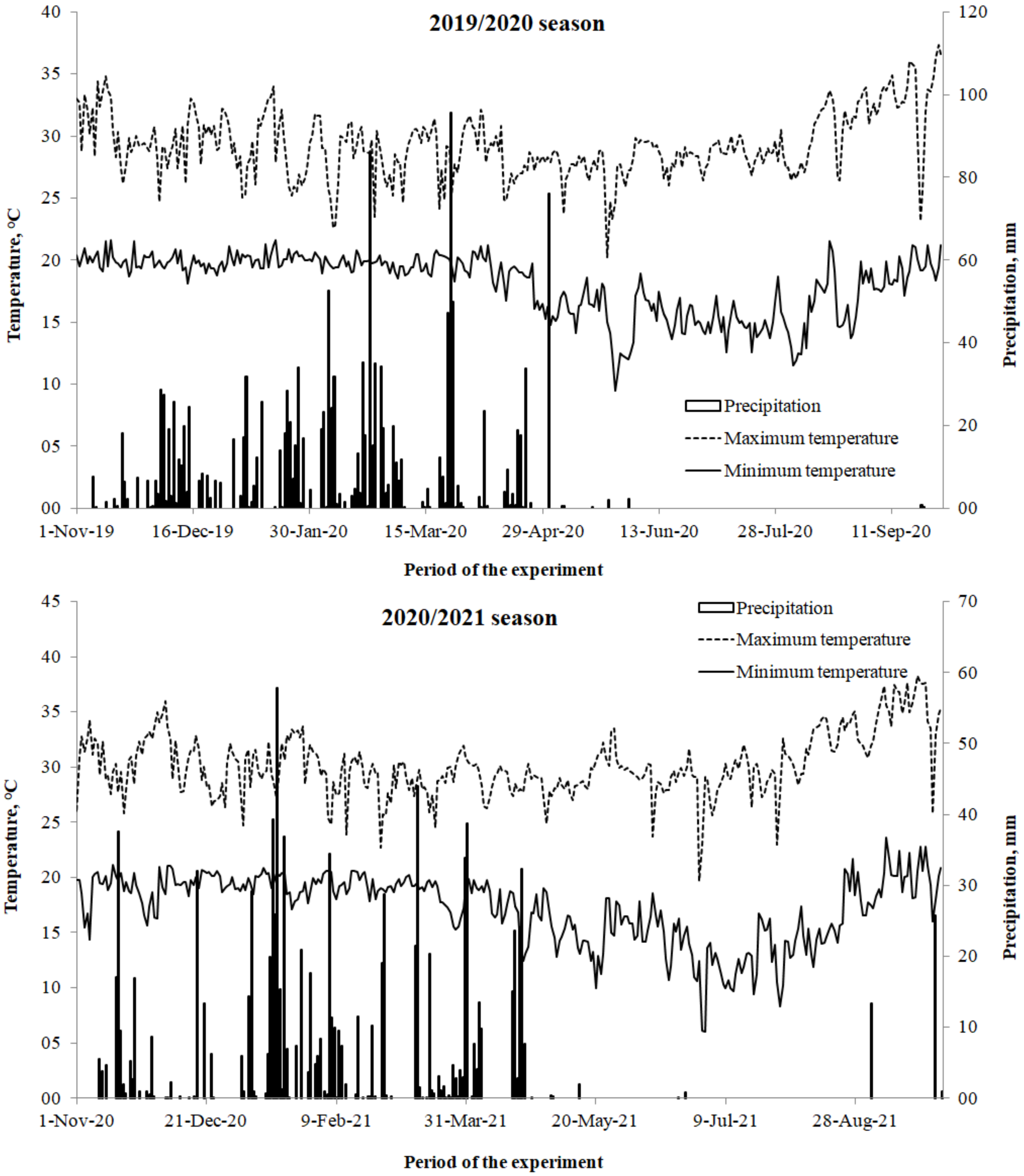
Field experiments were conducted in two seasons (2019/2020 and 2020/2021) at Fazenda Capivara, located in the municipality of Santo Antônio de Goiás, Goiás state, Brazil (16°28'00" S, 49º17'00" W, and altitude of 823 m). The climate is Aw (tropical savannah) according to the

Köppen classification, with the following two well-defined seasons: normally, the dry season extends from May to September (autumn/winter) and the rainy season extends from October to April (spring/summer). The historical average annual rainfall ranges from 1,500 to 1,700 mm. The historical average annual temperature is 22.7 °C, ranging annually from 14.2 °C to 34.8 °C. In addition, average daily temperature and precipitation were monitored during the experiment (Figure 1).

The soil was classified as an Acric Red Latosol (SANTOS et al., 2018). Prior to the experiment, soil chemical characteristics were determined at a depth of 0-0.20 m to characterize the soil in the experimental area. The following values were obtained: pH = 5.9 (H_2O), organic matter = 30.6 mg dm^{-3}, Ca = 2.03 $cmol_c$ dm^{-3}, Mg = 1.22 $cmol_c$ dm^{-3}, Al= 0.0 $cmol_c$ dm^{-3}, H + Al = 1.93 $cmol_c$ dm^{-3}, K = 109 mg dm^{-3}, P = 8.9 mg dm^{-3}, Cu = 1.1 mg dm^{-3}, Fe = 34.3 mg dm^{-3}, Mn = 11.2 mg dm^{-3}, and Zn = 5.4 mg dm^{-3}. In addition, the following sand, silt, and clay contents were observed: 496; 95; and 409 g kg^{-1}, respectively (clayey). Soil analysis was performed according to Claessen (1997). The experimental area has been cultivated in a no-till system for seven years with soybeans (summer), corn (off-season), and common bean (winter).

The completely randomized blocks experimental design was used, being arranged in a 2x4+1 factorial, with four replicates. Treatments consisted of the combination of the following two periods of nitrogen application: at sowing and recommended (four open leaves of corn and third trefoil in beans); and of the four following types of nitrogen fertilizers: 1. urea + NBPT + Zeolite; 2. urea + B + Cu + Zeolite; 3. Super N; and 4. Urea. Additionally, a control treatment (without N) was included. The experimental plots were 8 meters wide by 4 meters long. The central rows of the plots comprised the usable area, disregarding one row on each side of the plot and 0.50 m from each edge of the plot.

Figure 1. Maximum, minimum, and average temperatures and precipitation in the experimental area in the two crop seasons. Municipality of Santo Antonio de Goiás, Goiás state.



The fertilizers presented the following compositions: 1. Urea: 44.5% N; 2. Urea + NBPT + zeolite: 42.8% N; 3. Urea + B + Cu + zeolite: 43% N; and 4. Super N: 46% of N. The nitrogen values for application in the treatments were adjusted so that 150 kg ha^{-1} N was applied to the corn, cultivated in summer, and 90 kg ha^{-1} N was applied to the common bean, cultivated in winter. N was applied by broadcast application on the soil surface, with the anticipated fertilization being conducted right after crop emergence and topdressing being conducted when corn presented four open leaves and common bean was in growth stage V4 (third open trefoil).

Corn was sown on 11/28/2019 and on 12/14/2020, using the hybrid BM 855 PRO2, at a spacing of 0.90 m and six seeds per meter. Base fertilization in the two agricultural years was performed using 22 kg ha^{-1} N and 104 kg ha^{-1} of P_2O_5. K was not applied in the fertilization, as the soil already had presented a high K content (109 mg dm^{-3}). The harvests were carried out on 04/30/2020 and 05/10/2021 (148 and 142 days after emergence, respectively).

Common bean was sown on 06/08/2020 and on 05/27/2021, using the cultivar BRS FC402, at a spacing of 0.45 m and ten seeds per meter. Base fertilization was performed with 400 kg ha^{-1} of the 5-30-15 fertilizer. The harvests were carried out on 09/14/2020 and 09/09/2021, 93 and 99 days after emergence, respectively.

The management of corn and common bean crops was carried out in order to maintain the crops free from pests, diseases, and weeds. In common bean, irrigation water management was performed using the irrigaFeijao software (www.cnpaf.embrapa.br/irrigaFeijao).

In corn, grain yield was determined by harvesting the ears of plants from the usable area of each experimental unit, mechanical threshing them mechanically, and weighing their grains. The mass of the harvested grains was determined and the grain yield (kg ha^{-1}) was calculated after the water content was corrected to 130 g kg^{-1}.

In common bean, the following variables were determined: a) number of pods per plant, which was determined by counting the number of pods of ten plants collected randomly in each experimental unit during harvest; b) number of beans per pod, which was determined by counting the number of grains of the ten plants randomly collected during the harvest; c) 100 grain weight, which was determined by randomly collecting and subsequently weighing four samples of 100 grains of each experimental unit, with the correction of the water content of the grains to 130 g kg^{-1}; and d) grain yield, which was determined after the manual uprooting of plants from the usable area of each experimental unit, mechanical threshing, and grain weighing. The mass of the harvested grains was determined and the grain yield (kg ha^{-1}) was calculated after the water content was corrected to 130 g kg^{-1}.

The results were analyzed for data normality and homogeneity using the Lilliefors and Cochran and Barttlet tests, respectively. The results obtained were submitted to analysis of variance and, when necessary, the comparative test of LSD (least significant difference) means was performed for $p<0.05$. Analyzes were performed using the SAS statistical package.

Results

Corn crop

The effect of year was observed on corn yield (Table 1). Thus, yield was higher in the 2020/21 crop season (9,409 kg ha^{-1}) than in the 2019/20 crop season (8,668 kg ha^{-1}).

Regarding nitrogen sources, the yield was similar between seasons, with no statistical difference (Table 1). On the other hand, the control treatment, without the use of nitrogen, presented a significant difference from the treatments with nitrogen application, regardless of the source.

The period of application of the nitrogen fertilizer did not provide significant differences in relation to treatments (Table 1). Thus, nitrogen application at sowing resulted in a yield similar to that observed for the topdressing application of nitrogen.

Common bean crop

Significant differences in crop yields were observed for the variables number of pods/plant, number of grains/pod, and grain yield (Table 2). Thus, in the 2019 crop season, the values of number of pods per plant were lower (19.97) than in the 2020 crop season (25.73). In the variable number of grains per pod, the 2019 crop seasons (3.82) presented higher values than the 2020 crop season (3.54). One hundred grain weight was similar in both seasons. Yield was higher in the 2020 crop season (3,183 kg ha^{-1}) compared to the 2019 crop season (2,018 kg ha^{-1}).

Regarding nitrogen sources, it was verified that there were no differences in the variables number of pods per plant, number of grains per plant, and grain yield of common bean (Table 2). In 100 grain weight, the treatment with the Super N source provided the highest values, significantly differing from the treatment with urea + B + Cu + Zeolite.

The control treatment, without nitrogen application, showed a reduction in the variable 100 grain weight, which differed from the treatment with Super N (Table 2). Additionally, the control treatment presented the lowest grain yield and differed significantly from the other treatments with nitrogen application, regardless of the source used.

Regarding the period of nitrogen application in the common bean, there were no differences between treatments (Table 2). Thus, the variables number of pods per plant, number of grains per pod, 100 grain weight, and grain yield were not affected by nitrogen application at sowing or in topdressing.

Table 1. Corn grain yield as a function of the application of 150 kg ha^{-1} nitrogen using different sources (1. urea + NBPT + Zeolite; 2. urea + B + Cu + Zeolite; 3. Super N; and 4. urea) and periods of fertilizer application (at sowing and topdressing). Municipality of Santo Antônio de Goiás, 2019/20 and 2020/21 crop seasons.

Sources of variation	**Grain yield**
Year	kg ha^{-1}
2019/20	8668 b*
2020/21	9409 a
N source	
Urea	9178 a
Urea + NBPT + Zeolite	8967 a
Urea + B + Cu + Zeolite	9045 a
Super N	8962 a
Control	8255 b
Period of fertilization	
At sowing	9043 a
Topdressing	9033 a
Sources of variation	**Probability by F test**
Year (Y)	< 0.001
N source (S)	0.7127
Period of fertilization (P)	0.9468
Y x S	0.0560
Y x P	0.3282
S x P	0.3770
Y x S x P	0.3317

* Values followed by the same letter do not differ from each other by the Fischer's (LSD) test at p<0.005.

Table 2. Components of production and grain yield of common bean as a function of the application of 90 kg ha^{-1} nitrogen using different sources (1. urea + NBPT + Zeolite; 2. urea + B + Cu + Zeolite; 3. Super N; and 4. urea) and periods of fertilizer application (at sowing and topdressing). Municipality of Santo Antônio de Goiás, 2019/20 and 2020/21 crop seasons.

Source of variation	Pods/plant	Grains/pod	100 grain weight	Grain yield
Year	**Number**	**Number**	**Grams**	**kg ha^{-1}**
2019	19.97 b	3.82 a	23.87 a	2018 b*
2020	25.73 a	3.54 b	24.05 a	3183 a
N Source				
Urea	23.23 a	3.72 a	23.86 ab	2463 a
Urea + NBPT + Zeolite	21.43 a	3.57 a	23.88 ab	2600 a
Urea + B + Cu + Zeolite	23.31 a	3.71 a	23.47 b	2714 a
Super N	23.43 a	3.74 a	24.64 a	2625 a
Control	21.93 a	3.97 a	23.16 b	2178 b
Period of fertilization				
At sowing	21.88 a	3.69 a	23.73 a	2618 a
Topdressing	23.82 a	3.68 a	24.20 a	2583 a
Source of variation	**Probability by the F test**			
Year (Y)	<0.001	0.0335	0.5616	<0.001
N source (S)	0.5726	0.7769	0.0759	0.2888
Period of fertilization (P)	0.1025	0.9667	0.1399	0.7023
Y x S	0.3276	0.0660	0.5824	0.0675
Y x P	0.3283	0.2053	0.1907	0.8804
S x P	0.1010	0.8428	0.1231	0.0596
Y x S x P	0.3613	0.9098	0.6015	0.7578

* Values followed by the same letter do not differ from each other by the Fischer's (LSD) test at $p<0.005$.

Discussion

The use of enhanced-efficiency N sources did not provide significant increases in corn and common bean yields in relation to urea. This fact shows that for the conditions tested, coated urea sources behave similarly to urea. Similar results were obtained by Bernardes et al. (2015) and Silva Junior et al. (2020) with beans, by Carvalho et al. (2016) and Fageria and Carvalho (2014) with rice, by Prando et al. (2013) with wheat, and by Silva et al. (2012) with corn. Thus, it appears that under the conditions of this study, the modifications made to urea aiming to increase its efficiency were not effective in providing higher yields of corn and common bean grains in the two years evaluated, since urea provided results that were similar to those provided by other sources. Possible explanations for this lack of results of enhanced-efficiency fertilizers in relation to urea were the rains (corn) or irrigation (common bean) that occurred soon after the application of nitrogen fertilizers. This irrigation or rain condition up to three days after fertilization using nitrogen with urea is considered as ideal to obtain a better efficiency of N applied by broadcast on the soil surface, since N losses are minimal (PRANDO et al., 2013; FAGERIA, 2014) regardless of the source or form of the nitrogen fertilizer. Thus, for the conditions of the present study (i.e., irrigation or rainfall incorporating urea), the choice of the N source to be used would depend on the price. In this case, urea is more advantageous over the other nitrogen fertilizers tested.

The use of nitrogen provided significant increases in corn and common bean yields. Likewise, Fageria (2014), Carvalho et al. (2016) also reported an increase in the grain yield of agricultural crops with the use of N in Brazilian Latosols. Nitrogen is an important nutrient in crop development, and the use of nitrogen fertilizers in crops is directly related to increased yield (FAGERIA, 2014). Based on the results obtained, N application increases the yield of corn and common bean crops. Prando et al. (2013), who studied wheat, reported that when there were nine days in a row without rain after the application of various sources of coated urea, a difference was observed between N sources in relation to N loss compared to urea. This loss was caused by the hydrolysis of urea on the surface and, causing NH_3 volatilization loss. Even so, the authors did not observe differences in grain yield, probably as this loss of N from urea by volatilization was not enough to result in differences in crop performance. Thus, for these authors, the use of coated urea seems viable only in places with a risk of drought greater than nine days after the end of nitrogen topdressing.

Regarding the period of nitrogen application in corn and common bean crops, no significant differences were observed for grain yield. Regarding corn, Souza Neto et al. (2020) also found no difference in grain yield and other production components and plant characteristics when studying two periods of N application (at sowing and topdressing) at the V7 growth stage of the crop. Likewise, Nascente et al. (2016 and 2017) did not find significant differences in the common bean crop regarding the period of nitrogen application. This indicates that it is possible to carry out the anticipation of nitrogen fertilization in corn and common bean cultivated in a no-tillage system, since high doses of N in the sowing furrow can compromise the plant population (SANTOS; FAGERIA, 2007), and topdressing, in addition to increasing the cost of production, can cause damage to crops as a result of traffic of agricultural machinery (Kluthcouski et al., 2006).

Conclusion

Nitrogen sources and period of nitrogen application did not affect corn grain yield, production components, and common bean grain yield;

The application of nitrogen in corn or common bean provided significant increases in the grain yield of crops.

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