e-ISSN: 2177-5133
www.comunicatascientiae.com

Comunicata Scientiae 9(2): 202-210, 2018

DOI: 10.14295/CS.v9i2.2585

Article

Management of nitrogen fertilization in maize cultivated in succession to black oats in a temperate climate

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Abstract

The objective of this study was to verify early nitrogen (N) fertilization on maize cultivated in succession to black oats. We conducted three experiments, relating to the 2012/13, 2013/14, and 2014/15 growing seasons, at UFSC-Curitibanos, in a randomized complete block experimental design, with four treatments and four replicates. The treatments were N management strategies in which the amount of N applied to maize was split into pre-sowing, at sowing, and topdressing times: (T1) control with no N application; (T2) 2/3 - 1/3 - 0; (T3) 1/3 - 1/3 - 1/3; and (T4) 0 - 1/3 - 2/3. The biometrics and productive potential parameters of the crop were evaluated. Application of N, regardless of the treatment, increased the yield. In 2012/13, there were no significant differences between the ways in which the N application was split, although they produced a higher yield than the control, resulting in a mean yield of 5,008 kg ha^{-1}. In 2013/14, T2 was similar to T3 and T4, resulting in a yield of 9,858 kg ha^{-1}; in 2014/15, T3 and T4 were similar, with a mean yield of 12,466 kg ha^{-1}, while T2 resulted in a lower yield of 10,487 kg ha^{-1}. When 2/3 of the N is applied pre-sowing, it is only effective when it is associated with the occurrence of a drought period at an early developmental stage of the plants. In adequate rainfall conditions, the early application of N fertilization is only effective when combined with a further 1/3 of the amount of N at sowing, and later as a topdressing.

Keywords: *Avena strigosa*, nitrogen use efficiency, yield, *Zea mays*

Introduction

Soil fertility management, mainly in terms of nitrogen (N) fertilization, plus favorable climatic and biological conditions, are the main factors responsible for increases in maize (*Zea mays* L.) productivity. N is the nutrient required in the greatest amounts by the crop, and it is directly associated with final grain yield composition (Duete et al., 2008). Thus, improvements in N use efficiency (NUE) may result in increases in crop yield.

Several factors such as N losses due to ammonia volatilization, nitrate leaching, surface runoff, immobilization by microbial biomass (Fancelli, 2010), and nitrification and denitrification processes, which produce nitrous oxide (Almeida et al., 2015), determine whether this nutrient will be effective. Currently, the concern over the correct use of N is not only for the increase in productivity, but also from an environmental point of view, owing to the possibility of groundwater contamination, as well as atmospheric contamination, from excessive rates of application.

Among the strategies to maximize NUE and minimize environmental risk, splitting N fertilization stands out (Martins et al., 2014). This has the potential to improve NUE by maize, as well as to optimize the use of agricultural machinery (Lange et al., 2008); it enables the machinery to

Received: 18 November 2016
Accepted: 10 April 2018

be available for cultural practices in soybean, for example. Therefore, it is possible to split the N rate, with an application made pre-sowing when handling the winter crop, with the aim of increasing the N availability in the soil during the initial stages of crop growth, as well as providing a greater rationalization of machinery use and labor across the farm. However, this depends on favorable climatic conditions, and must be done at most 10-12 days before sowing (Fancelli, 2010). Any N applied as topdressing, is commonly added in vegetative stages V4 to V6.

The pre-sowing application is largely intended to supply the crop at the beginning of its development, when significant N losses can occur through microbial immobilization processes. This is because most of the maize is grown in no-tillage systems (NTS) in the south of the country, and occurs in succession to winter grasses, which have a high C/N ratio, so the N in the soil is immobilized by microorganisms, and hence, is not absorbed by the crop (Pöttker & Wiethölter, 2004; Lara Cabezas et al., 2007).

The aim of this work was to evaluate early application of nitrogen fertilizer on the agronomic performance of maize in succession to black oats, in no-tillage systems in a temperate climate.

Material and Methods

Three field experiments were carried out in the growing seasons 2012/13, 2013/14, and 2014/15, in the experimental area of the Campus de Curitibanos at the Universidade Federal de Santa Catarina (UFSC; 27° 16' 22'' S, 50° 30' 11'' W, 1050 m above sea level. The soil is a Cambissolo Háplico típico (Brazilian classification; Santos et al., 2013) or an inceptisol, with a clayey texture (550 g clay kg^{-1}). The area has been cultivated under NTS for more than five years, in soybean, ryegrass, maize, and black oats rotations. Climate is classified as temperate Cfb, according to Köppen. Mean annual rainfall is 1500 mm, and the mean temperature is 15 °C; rainfall and mean air temperature data during the three experiments are shown in Figure 1.

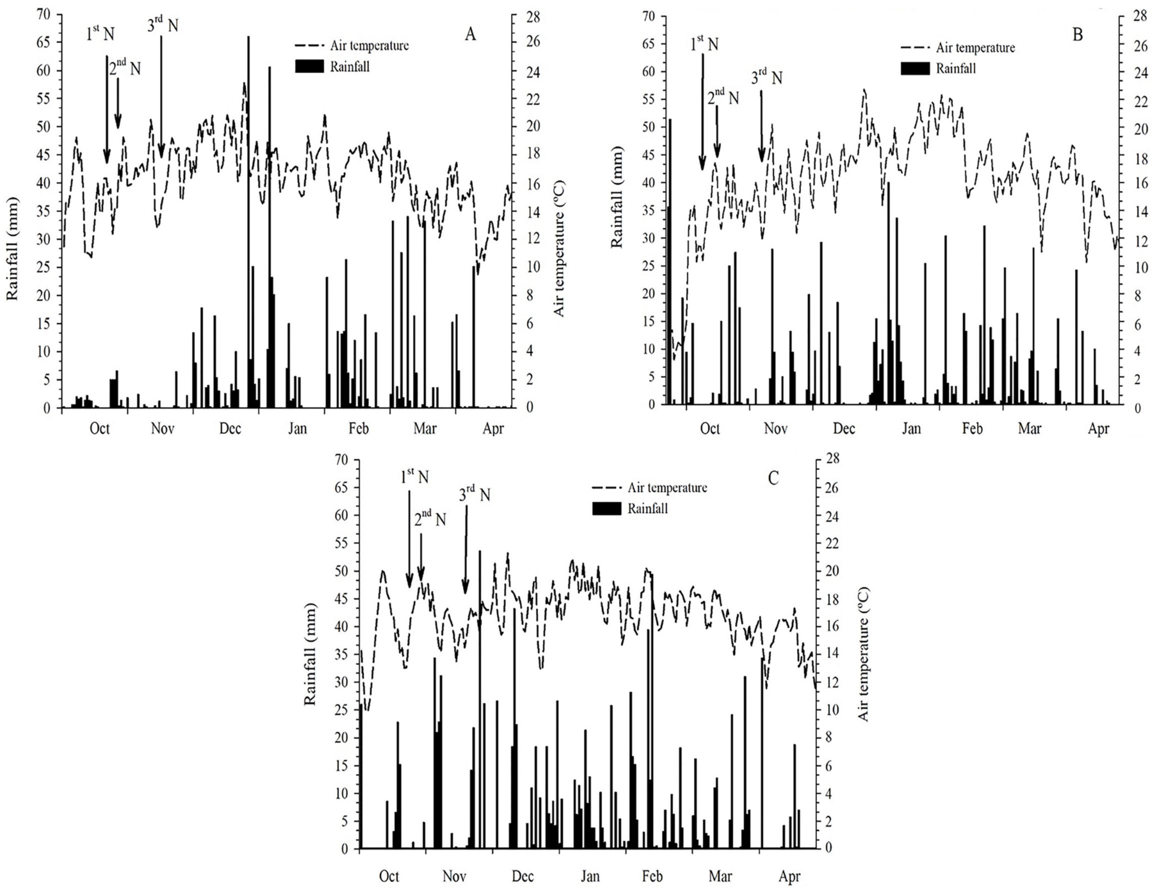

Figure 1. Rainfall (mm) and mean air temperature (°C) during the experimental periods. A = 2012/13; B = 2013/14; C = 2014/15. The arrows indicate the times of application of nitrogen in the maize crop: 1st N = pre-sowing N application; 2nd N = N application at sowing; 3rd N = N application at V4 stage.

The experimental design was a randomized complete block, with four treatments and four replicates. Plots were formed by sowing 8 rows of maize, 5 meters in length with 0.5 m between each, totalling 20 m^2. The useful area of each plot was 9 m^2, which excluded the 2 border rows, and 1 m at the end of each row. After the black oat growth in the winter of 2012, soil analysis was carried out in order to determine the recommended N rate (Table 1).

Three consecutive experiments were performed, where maize was cultivated in succession to black oats, with plots and treatments occupying the same sites in the field. Black oats were planted in NTS in May of each year at a seed density of 80 kg ha^{-1}, with 0.17 m between rows. No fertilizer was applied in winter. Oat desiccation management was performed 20 days before the maize sowing, in all experiments, using Glyphosate herbicide.

Table 1. Chemical characterization of the 0.0-0.2 m layer, prior to planting the experiment.

$OM^{(a)}$	pH	$P^{(b)}$	$K^{+(b)}$	$Ca^{2+(c)}$	$Mg^{2+(3)}$	$Al^{3+(c)}$	V	m
g dm^{-3}	$CaCl^2$	mg dm^{-3}	-----------cmolc dm^{-3}----------				--------%-------	
53.61	6.6	7.7	0.23	7.98	3.91	0.00	85.97	0.00

OM= Organic matter; V = Base saturation; m = Aluminum saturation. (a) Walkley & Black (1934); (b) Mehlich-1; (c) 1M KCl; pH measured in a solution of 0.01M CaCl2.

The N rate used was 130 kg of N ha^{-1}, with urea (45% N) as its source. The amount and timing of applications defined the treatments, with the amount of N in kg ha^{-1} split into the following applications: pre-sowing 4 days before the maize was sowed, at sowing, and as a topdressing at the V4 stage, respectively: (T1) control without N application; (T2) 2/3 - 1/3 - 0; (T3) 1/3 - 1/3 - 1/3; and (T4) 0 - 1/3 - 2/3.

In the 2012/13 experiment, maize was sowed on October 25, 2012, using the hybrid Biogene 7046; in the 2013/14 experiment, maize was sowed on October 8, 2013, using hybrid DKB 245; in the 2014/15 experiment, maize was sowed on October 24, 2014, using the hybrid AS 1656 PRO3. In all experiments, a density of 70,000 plants ha^{-1} was maintained. During the experimental periods, cultural treatments were carried out following technical recommendations according to the crops' requirements.

Morphological parameters of the crop were evaluated at the R2 stage, through sampling of five plants from the useful area of each plot. The parameters evaluated were: plant height, stem diameter at 20 cm above the soil, and the height of the main ear.

The variables that comprise maize yield were evaluated at the time of grain physiological maturation, through the sampling of 10 ears from the useful plot area. Number of ears per square meter, ear length, number of rows per ear, number of grains per row, and mass of a thousand grains were evaluated. To determine grain yield, an area of 15 m^2 was harvested, with grain moisture corrected to 14%.

The results were submitted to analysis of variance. When significant differences were observed, treatments were compared by Tukey test with a 5% probability level.

Results and Discussion

Splitting the application of N in maize significantly affected the crop variables in all experiments (Table 2). An absence of significance was observed only for the number of ears per square meter in 2012/13 and 2013/14, the number of rows per ear in 2012/13, and the mass of a thousand grains in 2014/15.

Plant height was not affected by the ways of splitting the N application, which differed only from the control (Table 3). The same behavior was observed for the height of the main ear and for the stem diameter (Table 3).

The increase in plant height observed in treatments with N, in comparison to the control, is an outcome of adequate N plant nutrition. Nitrogen directly influences N levels in crop leaves, maximizing the photosynthetic process, increasing cell division and expansion (Valderrama et al., 2011), and favoring the development of leaf area (Gomes et al., 2007) and root systems, which result in greater growth, thus increasing this variable.

It is possible to relate the lower plant heights in the 2012/13 experiment to water stress conditions during this period, which lasted until the V6 stage (Figure 1A). Maize plants under water deficiency show reduced cell elongation and division, leaf expansion, transpiration, and photosynthetic activity, and restrict the translocation of photoassimilates (Sangoi et al., 2010 b). In addition, because different hybrids were used in each experiment, there may be inherent variation in morphological parameters, even when plants were subjected to the same rate of N (Carvalho et al., 2011); however, no differences were found between the different ways of splitting the N application, regardless of the hybrid used. Similar data were found by Schoninger et al. (2012) where, by testing application times and N sources, no significant differences occurred among times, for height of main ear, plant height, or stem diameter.

Table 2. Analysis of variance (mean squares) for morphological parameters and yield components of maize crops in three successive years.

Sources of variation	DF	Mean Squares									
		PH (m)	HME (m)	SD (cm)	NEM	EL (cm)	NRE	NGR	NGE	MTG (g)	Yield (kg ha^{-1})
2012/13											
Treatments	3	0.07**	0.13**	12.62**	1.08ns	22.81**	0.18ns	41.64*	12922.21*	1692.56**	7718192.834
Error	9	0.01	0.00	1.71	0.64	0.04	0.24	7.78	2442.67	74.44	13177.28
Mean		1.90	0.88	23.37	3.41	8.51	16.12	34.97	564.41	338.95	4315.00
CV (%)		4.69	7.17	4.96	23.51	2.25	3.00	7.98	8.76	2.55	2.56
2013/14											
Treatments	3	0.23**	0.12**	66.71**	1.38ns	26.04**	0.47**	117.10**	34053.79**	1480.22*	272855618.64**
Error	9	0.01	0.01	2.11	0.52	0.16	0.06	1.12	317.99	262.02	324998.04
Mean		2.21	1.32	25.48	5.25	14.89	15.72	32.51	512.02	365.77	9063.94
CV (%)		2.82	3.02	5.70	13.70	2.65	1.57	3.25	3.48	4.43	6.29
2014/15											
Treatments	3	0.37**	0.21**	14.12**	10.46*	36.82**	1.45*	166.60**	56647.81**	411.96ns	67718166.22**
Error	9	0.09	0.02	0.55	1.64	1.13	0.35	7.19	2659.32	385.65	463098.69
Mean		2.28	1.31	20.65	8.43	11.62	16.85	24.27	412.01	305.11	9809.58
CV (%)		7.19	5.73	3.59	15.21	9.17	3.52	11.05	12.51	6.44	6.94

PH = plant height; HME = height of main ear; SD = stem diameter; NEM = number of ears per square meter; EL = ear length; NRE = number of rows per ear; NGR = number of grains per row; NGE = number of grains per ear; MTG = mass of thousand grains; Yield = grain yield. * significant at 5% and ** significant at 1% probability; ns = not significant.

Table 3. Morphological parameters of maize cultivated under different ways of splitting N applications, across three years.

Splitting	Experiments (years)		
	2012/13	2013/14	2014/15
	Plant Height (m)		
Control	1.71 b	1.84 b	1.83 b
2/3 - 1/3 - 0	1.99 a	2.34 a	2.40 a
1/3 - 1/3 - 1/3	1.93 ab	2.31 a	2.51 a
0 - 1/3 - 2/3	1.95 a	2.33 a	2.37 a
	Height of main ear (m)		
Control	0.73 b	1.07 b	0.97 b
2/3 - 1/3 - 0	0.96 a	1.36 a	1.36 a
1/3 - 1/3 - 1/3	0.91 a	1.40 a	1.43 a
0 - 1/3 - 2/3	0.93 a	1.45 a	1.46 a
	Stem diameter (mm)		
Control	23.80 b	19.40 b	17.90 b
2/3 - 1/3 - 0	27.65 a	27.22 a	21.10 a
1/3 - 1/3 - 1/3	26.60 a	28.20 a	21.50 a
0 - 1/3 - 2/3	27.45 a	27.10 a	21.10 a

Means followed by the same lowercase letter within a column do not differ significantly from each other by the Tukey test at 5% probability.

Greater stem diameter values are interesting because they make plants difficult to break, and protect against lodging (Zucareli, et al., 2013); this can be directly reflected in the grain yield. However, the lowest values for stem diameter observed in this study occurred in the year with the highest grain yield (experiment 2014/15). This may be due to a higher translocation of nutrients from stem to reproductive structures, since in that year, there were more ears per square meter (Table 4).

For the number of ears per square meter (Table 4), there were no significant differences between the treatments in the 2012/13 and 2013/14 experiments; however, for the 2014/15 experiment, the control treatment resulted in lowest number of ears, and the other treatments did not differ among themselves (Table 4).

Table 4. Number of ears per square meter in maize cultivated under different ways of splitting N applications, across three experiments (years).

Splitting/Experiment	2012/13	2013/14	2014/15
Control	3.05 a	4.64 a	6.06 b
2/3 - 1/3 - 0	3.15 a	4.87 a	8.70 ab
1/3 - 1/3 - 1/3	3.25 a	4.62 a	9.44 a
0 - 1/3 - 2/3	4.17 a	5.87 a	9.50 a

Means followed by the same lowercase letter in the column do not differ significantly from each other by the Tukey test at 5% probability.

The lowest numbers of ears per square meter in the 2012/13 and 2013/14 experiments (Table 4), are related to the low temperatures and low rainfalls observed in those years (Figure 1A and B), causing failures in the plant stand. In these experiments, the mean air temperatures for the 30 days before sowing were 15.4 and 14.3 °C, respectively, whereas for 2014/15 it was 16.8 °C (Figures 1A, B, C). This corroborates the results of Sangoi et al. (2010 b) and Sbrussi and Zucareli (2014), who observed that failures and delays in germination at temperatures below 16 °C reduced the final stand of plants and consequently, the number of ears. In addition, low soil moisture, due to lower rainfall, may also have affected seed germination and seedling permanence.

For all of the experiments, ear length was greater in treatments with N than in the control (Table 5). Ways of splitting N application did not differ, except for 2014/15, where T2 presented intermediate values between the control and the other treatments. The number of grains per row and the number of grains per ear increased significantly when N was applied in all experiments, but with no differences among them (Table 5). For the number of rows per ear in 2013/14, the control and T2 did not differ from each other, and were similar to T3. In 2014/15, ways of splitting N application resulted in no differences.

Table 5. Characteristics of ears of maize cultivated under different ways of splitting N applications, across three experiments (years).

Splitting	Experiments (years)		
	2012/13	2013/14	2014/15
		Ear length (cm)	
Control	4.92 b	11.12 b	7.30 c
2/3 - 1/3 - 0	9.62 a	15.52 a	11.90 b
1/3 - 1/3 - 1/3	9.72 a	16.42 a	13.47 a
0 - 1/3 - 2/3	9.75 a	16.50 a	13.95 a
		Number of rows per ear	
Control	15.87 a	15.40 b	15.95 b
2/3 - 1/3 - 0	16.32 a	15.60 b	17.20 a
1/3 - 1/3 - 1/3	16.02 a	15.67 ab	17.15 a
0 - 1/3 - 2/3	16.27 a	16.20 a	17.10 a
		Number of grains per row	
Control	30.35 b	24.62 b	14.90 b
2/3 - 1/3 - 0	37.82 a	33.32 a	25.17 a
1/3 - 1/3 - 1/3	36.22 a	36.20 a	29.02 a
0 - 1/3 - 2/3	35.47 a	35.90 a	27.97 a
		Number of grains per ear	
Control	483.38 b	379.39 b	283.36 b
2/3 - 1/3 - 0	616.98 a	519.87 a	433.08 a
1/3 - 1/3 - 1/3	579.73 a	567.31 a	498.58 a
0 - 1/3 - 2/3	577.62 a	581.52 a	478.28 a

Means followed by the same lowercase letter in the column do not differ significantly from each other by the Tukey test at 5% probability.

The N application promoted increases in the number of rows per ear except for in the 2012/13 crop (Table 5). These results are in agreement with Gazola et al. (2014), who report the influence of N on incremental changes in this variable, consequently resulting in a higher amount of grain per ear and a higher yield. The other variables were also increased by N, regardless of the ways of splitting its application. These data corroborate those reported by Meira et al. (2009), who did not observe differences for these variables when splitting application times.

Maize plants have a low compensatory capacity, so ear length has a minimal influence on grain yield, in conditions with few ears per unit area (Fancelli, 2010). The same author concluded that the main factors that define yield are the number of ears and grains per unit area, not their size, as these components are influenced by the management practices adopted from the V4 stage to crop flowering. This behavior is evidenced in the present study, where in 2013/14 the ear components (Table 5) were higher than in 2014/15, but in the latter experiment, there were more ears per square meter (Table 4), resulting in a higher yield than in 2013/14 (Table 6). These data corroborate those of Sangoi et al. (2010a), where larger ears were not necessarily indicative of a high grain yield per unit area, but were an outcome of a low plant density.

The mass of a thousand grains was not influenced by the ways of splitting the N application, but in 2012/13 and 2013/14, the control values were lower than those of the N treatments (Table 6).

Table 6. Mass of a thousand grains and grain yield of maize cultivated under different ways of splitting N applications, across three experiments (years).

Splitting/Experiment	2012/13	2013/14	2014/15
		Mass of a thousand grains (g)	
Control	309.00 b	340.30 b	299.65 a
2/3 - 1/3 - 0	345.65 a	384.50 a	293.60 a
1/3 - 1/3 - 1/3	345.22 a	362.52 ab	312.37 a
0 - 1/3 - 2/3	355.92 a	375.77 a	314.80 a
		Grain Yield (kg ha^{-1})	
Control	2235.75 b	5211.075 c	3817.15 c
2/3 - 1/3 - 0	4937.25 a	10407.05 ab	10487.85 b
1/3 - 1/3 - 1/3	5135.00 a	10896.00 a	12080.27 a
0 - 1/3 - 2/3	4315.00 a	9063.94 b	12853.15 a

Means followed by the same lowercase letter in the column do not differ significantly from each other by the Tukey test at 5% probability.

The lack of differences in the mass of a thousand grains 2014/15 may be related to the fact that this variable is highly dependent on genetic and environmental factors, and is barely affected by management and fertilization, as mentioned by Borrás and Otegui (2001). However, in some studies, maize mass of a thousand grains variation has been observed due to soil and climatic conditions (Caires & Milla, 2016) and N rates (Soratto et al., 2010), corroborating with our findings in 2012/13 and 2013/14. In work conducted by Rocha et al. (2014) in an oxisol, there was also no significant difference for this variable when splitting the N application.

Maize grain yield was influenced by N application, and regardless of the experiment, treatment values were greater than control values (Table 6). In 2012/13 there were no significant differences among the N treatments, with an average grain yield of 5,008 kg ha^{-1}. Similar results were observed by Ceretta et al. (2002) and Rocha et al. (2014), which showed no difference in maize yield among different N application times. This lack of difference, occurs mainly in clayey soils with a medium to high organic matter content (Ceretta et al., 2002), such as the soil in this study (Table 1). The absence of differences among these treatments and the low yields are explained by the water deficit in that experiment (Figure 1A), because under low soil moisture conditions, the organic matter mineralization rate is lower, and consequently, N availability for crops is decreased (Aita et al., 2006). In addition, water availability, especially in September to November in which there was only 83.4 mm of precipitation (Figure 1A), was inferior to crop demands, reducing their respiratory rate and leaf area, and thus affecting yield (Sangoi et al., 2010b).

In 2013/14, T3 resulted in a higher yield (10,896 kg ha^{-1}), which was similar to that of T2 (10,407 kg ha^{-1}); both were higher than T4 (9,742 kg ha^{-1}) (Table 6). This higher yield may be related to the fact that N uptake was more efficient when its amount was divided equally among three application times. Similar results were found by Basso and Ceretta (2000), in years with normal rainfall, where N application pre-sowing and in topdressing were more efficient.

In the study on splitting N application in maize carried out by Pottker and Wietholter (2004), they found that splitting it into three application times resulted in highest grain yield, corroborating the data from the present study. For Kunz et al. (2007), a water deficit can harm the crop at any stage of development, but for 2013/14 the rainfall was well distributed (Figure 1B) without long periods of drought, i.e., different conditions from 2012/13. The lower yield from the treatment with 2/3 of N at the V4 stage, is related to the increase in mean air temperature at that time (Figure 1 B), which may have accentuated the processes of N loss through ammonia volatilization (Viero et al., 2014), reducing the NUE, and consequently reducing grain yield.

In 2014/15, treatments 3 and 4 did not differ, with an average yield of 12,466 kg ha^{-1} (Table 6). This behavior demonstrates that the lack of available N for the plant at the V4 stage results in yield losses, since this is one of the critical stages for maize, at which the productive potential is defined (Santos et al., 2010b). This agrees with results found by Santos et al. (2010a), in which pre-sowing application of N, resulted in a lower yield of maize compared to application at the V4 stage. The lower maize yield in T2 is owing to possible losses, mainly due to nitrate leaching (Rocha et al., 2014), caused by excessive rainfall during this period (Figure 1C). The higher maize yields in this experiment may be related, among other factors, to the utilization of the residual N of straw from previous crops. Although the mineralization occurs slowly in straw with a high C/N ratio, such as oats and maize, as the decomposition of this material occurs, N will be released. Aita et al. (2006) observed that the mineralization of one-third of the C of oat straw occurred in the three months after harvest, demonstrating the high potential for retention of N in this straw. Crusciol et al. (2008), studying the decomposition rate of oat straw over time, adjusted linear functions, and showed that at 13, 35, and 53 days after desiccation, the amount of the initial dry mass remaining was 72.2%, 56%, and 33.6%, respectively.

The application of 2/3 of the N rate during pre-sowing appears to be a risky practice, characterized by a high level of unpredictability. Many factors that influence the success of this practice cannot be effectively controlled, such as the immobilization of N by microorganisms, the C/N ratio of straw, the soil type, and the climatic characteristics, which mainly relate to the rainfall regime (Fancelli, 2010). Fontoura and Bayer (2009) suggest a management strategy for the N fertilization of maize when the preceding crop presents a high C/N ratio, which consists of applying higher rates of N at the time of sowing. This ensures there will be sufficient N to accelerate the decomposition of residues, reducing the period of microbial immobilization, and providing the amount of N required for the crop.

Conclusions

Splitting the nitrogen fertilization of a maize crop, with 2/3 of the rate applied pre-sowing, associated with subsequent fertilizer application at time of sowing, tends to be viable in summer drought conditions.

In suitable rainfall conditions, during the crop cycle, early application of nitrogen fertilizer, using 1/3 of the rate, is only effective when associated with the subsequent application of 1/3 of the rate at sowing, and a further 1/3 at the V4 stage.

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