NITROGEN FERTILIZATION MANAGEMENT IN NO-TILLAGE MAIZE WITH DIFFERENT WINTER CROPS

MANEJO DA ADUBAÇÃO NITROGENADA NO MILHO COM DIFERENTES PLANTAS DE INVERNO, SOB PLANTIO DIRETO

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ABSTRACT: The nitrogen (N) utilization by maize grown in a no-tillage system is dependent on the quality of the preceding crop residues, which may promote differences in N fertilization efficiency with respect to time. Thus, the purpose of this study was to evaluate the nutritional state, dry matter production and grain yield of maize grown in a clayey soil (Typic Acrustox) under a no-tillage system. The split-plot experimental design was set up in randomized complete blocks with three replications, in which the main plot was treated with different N application strategies and the split-plots were planted with winter crops (soybean and maize). The fertilizer strategies (rate: 120 kg ha^{-1} of N) used were as follows: (0 – 0), (20 – 100), (60 – 60), (120 – 0) and (0 – 120), with the first number corresponding to the rate of N (kg ha^{-1}) applied before planting and the second number corresponding to the top dressing rate (V4-5 stage). Nitrogen fertilization raised the N content (in shoots and leaves) and maize yield (in the shoot dry matter and grain). The maize grown after soybean had both greater N concentrations and production (dry matter and grain) relative to the maize grown after maize. Applying 120 kg ha^{-1} N did not significantly affect the evaluated variables, regardless of the winter crop.

KEYWORDS: Split application of nitrogen. Preplanting fertilization. Tropical soil. Soybean. *Zea mays*.

INTRODUCTION

Nitrogen is the nutrient most taken up by maize, and its availability to plants is regulated by immobilization, mineralization, leaching, volatilization and denitrification (CANTARELLA, 2007). In no-tillage systems, plant residues have slower decomposition times as a result of less contact with the soil because there is a lack of soil turnover (SÁ, 1996).

Moreover, the quality of the plant residue from the preceding crop, principally with regard to the C/N ratio, influences the intensity of the immobilization/mineralization processes and leads to differences in maize N utilization (AMADO et al. 2002; OHLAND et al., 2005).

Gramineae plants have been used the most as cover crops in no-tillage systems because of their greater dry matter production and C/N ratios compared with leguminous plants and because they provide greater soil protection for a longer time (AITA et al., 2001). However, planting leguminous plants during the winter crop season could be an interesting alternative to N supplementation for the crop that follows (SÁ, 1996). Aita et al. (2001) evaluated the use of different winter crops, and they were interested in reducing the quantity of N applied to maize when it was grown after leguminous plants. Bundy et al. (1993), Ding et al. (1998) and Varvel e Wilhelm (2003) showed that growing soybeans prior to maize provided considerable quantities of N that could be used by the succeeding crop.

Growing winter crops is especially helpful for farmers who have an irrigation system, especially when these crops have a dual purpose (straw and grain production). Soybean and maize are currently being used in these areas.

The N application strategy may influence maize utilization of this nutrient under a no-tillage system. Nitrogen fertilization recommendations normally suggest using a split application and providing fertilizer as close as possible to the plant phenological stage of greatest demand, which is intended to reduce possible N losses, especially through leaching (CANTARELLA, 2007).

Nevertheless, applying the whole N quantity at preplanting in some situations has proven to be a good alternative for optimizing machinery use on the property. This application modality is based on the temporary immobilization of N by microorganisms and later the mineralization/release of this nutrient by the maize crop (BASSO; CERETTA, 2000). Sá (1996), Pötteker e Wiethölter

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(2000) and Wolschick et al. (2003) reported the maize yield was not significantly affected by differing the N application timing.

However, when maize is planted following a legume crop, a reduced application rate or no additional need for N during the initial crop phases may be assumed, with a suggested single application of this nutrient in the top dressing. At more advanced stages when the root system is more developed, the use of N released by the previous crop and of N applied by mineral fertilization may be improved (STRIEDER et al., 2006).

In southern Brazil, there is already a recommendation for maize N fertilization under the no-tillage system considering, among other factors, the preceding crop (AMADO et al., 2002). Nevertheless, the studies that produced this recommendation were undertaken in edaphoclimatic conditions very different from the conditions in the northern and northeastern parts of the state of São Paulo. Furthermore, the few existing studies from other regions of the country were undertaken in areas that had adopted the no-tillage system for a few years.

Therefore, the main objective of this study was to evaluate the nutritional status and productivity (dry matter shoots and grain) of maize grown in a no-tillage area (summer crop) in terms of the N application strategies and different winter crops (soybean and maize) within the edaphoclimatic conditions of the state of São Paulo.

MATERIAL AND METHODS

The experiment was conducted under field conditions in the Experimental Station of the São Paulo State University (UNESP) located at Jaboticabal, SP (Brazil) in a clayey soil (Typic Acrustox), and its soil fertility attributes are presented in Table 1. The area has had a history of no-tillage since 1990, with maize planted as a summer crop, which is usually sown during the second fortnight of November each year. Until 1998, the cover crops were composed of spontaneous vegetation. Starting that year, maize and soybean were employed as winter crops, both under supplemental sprinkler irrigation.

Table 1. Chemical attributes for purposes of soil fertility*.

Depth	pH ($CaCl_2$)	OM	P (resin)	K	Ca	Mg	H+Al	CEC	V
m		g dm^{-3}	mg dm^{-3}	------------- mmol$_c$ dm^{-3} ------------					%
0 - 0.1	6.0	36	98	4.6	71	25	24	124.6	81
0.1 - 0.2	5.8	28	86	2.9	57	20	25	104.9	76

*Analyses performed according to Raij et al. (2001); Organic matter (OM): Walkley-Black method; pH in 0.01 mol L^{-1} $CaCl_2$; phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg): extracted with ion exchange resin; potential acidity (H + Al): SMP buffer method; cation exchange capacity at pH 7.0 (CEC); Base saturation of the CEC (V).

The winter crops were planted in April. Plant sampling (maize and soybean) was performed before the plants were desiccated, and the plants were cut at ground level to evaluate the dry matter production and N contents of the shoots to estimate the accumulation of this nutrient by the winter crop plants. The plants were desiccated by the application of glyphosate herbicide (1,920 g ha^{-1} of the active ingredient) immediately after sampling. The maize grain development was in the blister stage (R_2), and soybeans were at the full flowering stage (R_4). Afterwards, the plants were chopped up with the use of a triton-type mechanical chopper and uniformly spread across the crop area.

The split-plot experimental design was set up in randomized complete blocks with three replications. The main plot was treated with different N applications, and the split-plots contained the winter crops (soybean and maize). The plots had a total area of 72 m^2 (14.4 x 5.0 m) and were separated by a 1.0 m border; the split-plots consisted of a total area of 36 m^2 (7.2 x 5.0 m), with a useful area of 27 m^2 for the evaluations.

The N fertilization strategies (total rate: 120 kg ha^{-1} N) were as follows: (0 – 0), (20 – 100), (60 – 60), (120 – 0) and (0 – 120), with the first number corresponding to the rate of N (kg ha^{-1}) applied at preplanting and the second number to the rate applied as top dressing. The preplanting application was performed seven days before planting the maize (spring/summer) and top dressing occurred when the maize plants had four to five completely unrolled leaves (V4-5 stage). The N source was ammonium nitrate, and both applications were performed through broadcast fertilization over the entire area.

Together with N fertilization during preplanting, 60 kg ha^{-1} K_2O was applied in the form of potassium chloride, which was also broadcast over the total area. An additional 80 kg ha^{-1} P_2O_5

was applied in the planting furrow in the form of single superphosphate.

Seventy days after the management of the winter crops, maize was planted using single cross hybrid 8480 Dow AgroSciences seeds with a row spacing of 0.90 m, with the intention of reaching a final population of 55,000 plants ha^{-1}.

At the time of tasseling (50% of plants tasseled), the leaves were sampled for N nutritional diagnosis. The center third of the leaf at the base of the ear was collected from 20 plants per split-plot. When the maize was in the R3 phenological stage, ten plants per split-plot were collected and cut at ground level to determine the dry matter and N concentration in the aboveground part of the maize. All collected plant material was taken to the laboratory, adequately washed (using the following sequence of operations: diluted detergent solution, running tap water, 0.1 mol L^{-1} HCl solution, running tap water, distilled water), dried in a laboratory oven at 65°C and weighed for dry matter determination. The N concentrations were analyzed in accordance with Bataglia et al. (1983).

The grain yield was estimated by harvesting the ears from the four central rows of each split-plot. The data were later standardized to a moisture content of 130 g kg^{-1}.

The data were submitted to an analysis of variance by F test in accordance with the adopted design. When significant differences were observed, a Tukey-test was used to determine significant differences ($P < 0.05$) among means.

RESULTS AND DISCUSSION

During the maize crop cycle (spring/summer), there were no prolonged drought periods that could limit crop development and hurt grain yield. From the N application at preplanting to stage V4-5 (beginning at the time of high N demand in maize plants), a rainfall of 173.7 mm was observed. From the application at preplanting to the planting of maize (spring/summer), 25.8 mm of rainfall was recorded. The accumulated rainfall during the period from maize planting until harvest was 1,069.4 mm (Figure 1).

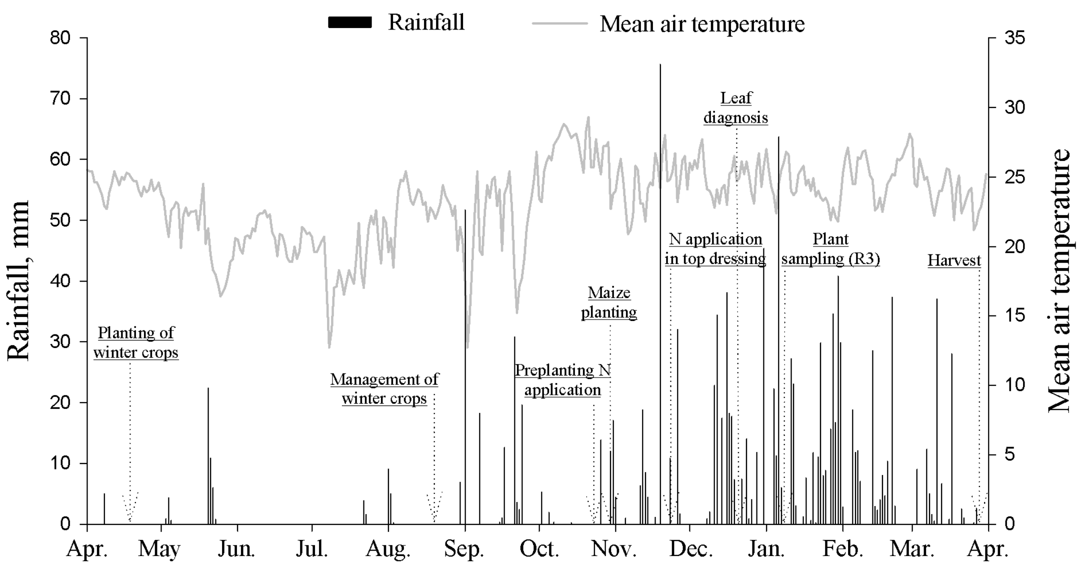

Figure 1. Rainfall, mean air temperature and activities performed during the experimental period.

The dry matter production of the winter crops was 3,985 and 6,884 kg ha^{-1}, and the accumulation of N in the shoots was 93.6 and 70.9 kg ha^{-1} of N for soybeans and maize, respectively.

In spite of having lower dry matter production, the soybean accumulated and therefore potentially supplied a greater quantity of N to the following crop than the maize. Nevertheless, despite the climatic conditions of the region, which favor the rapid decomposition and mineralization of plant residues, a large part of this quantity was likely not made available during the maize crop cycle. This N was unavailable because the crop system is no-tillage, and the residues, therefore, have less contact with the soil, resulting in a lower speed of residue decomposition compared with that of conventional tillage (SÁ, 1996; AMADO et al., 2002).

Maize plants grown after soybean had higher N concentrations in the aboveground parts than those grown after maize (Table 2). This finding is most likely related to the C/N ratio of the residues, which controls the speed of their decomposition. Because soybean have a C/N ratio lower than that of maize, they decompose more rapidly and thus lead to less mineral N immobilization (SÁ, 1996; AMADO et al., 2002). Apparently, the supply of N from a preceding soybean crop is more synchronized with the maize N demand. In addition, because of the greater supply of N from soybeans to the system, there may have been greater mineralization of the soil organic matter, which is an effect known as “priming” (RAO et al., 1992). Through this trend, changes may have occurred in the characteristics of the root system that improved water and nutrient utilization (JENKINSON et al., 1985; KRISTENSEN; THORUP-KRISTENSEN, 2007). Normally, this effect is attributed to the application of mineral fertilizers, but Silva et al. (2006) observed the same effect when they used Crotalaria as a cover crop.

When N was not applied (0 - 0), lower N contents were observed in the aboveground parts of the maize. Nevertheless, the N concentration following fertilization was not dependent on the application strategy (Table 2).

Table 2. Nitrogen concentrations in the maize shoots relative to the N application strategies and winter crops.

Winter Crop	Nitrogen application (kg ha^{-1}) [1](0 – 0)	(20 – 100)	(60 – 60)	(120 – 0)	(0 – 120)	Mean
	N in the shoot (g kg^{-1})					
Maize	10	16	16	16	16	15 b
Soybean	14	16	16	17	17	16 a
Mean	12 B	16 A	16 A	16 A	16 A	
CV% (plot) = 7.50	CV% (split-plot) = 6.08					

[1] the first and second numbers correspond to the rate of N applied at preplanting and when the plants had four completely unrolled leaves, respectively. Means followed by different letters (capital letters in the lines and small letters in the columns) differ significantly according to the Tukey's test at 5% probability.

Following N fertilization, the dry matter production of the maize shoots increased significantly. Nevertheless, the split application of this nutrient did not alter the accumulated dry matter. When maize was grown after soybeans, the dry matter production was significantly greater than that observed in the maize grown after maize (Figure 2).

The N concentrations in the leaves sampled at the time of tasseling were influenced by the N application strategies and winter crops. Figure 3A shows that in the controls (without N), the maize plants had leaf N concentrations significantly inferior to the treatments in which the nutrient was applied, with the highest being in the maize grown after maize. Comparing only the results of the N fertilization treatments, the N concentrations in the leaves did not experience any influence from the different nutrient application strategies. The concentrations observed in these treatments were within the range of contents considered adequate by Cantarella et al. (1996), which varied from 27 to 35 g kg^{-1} N.

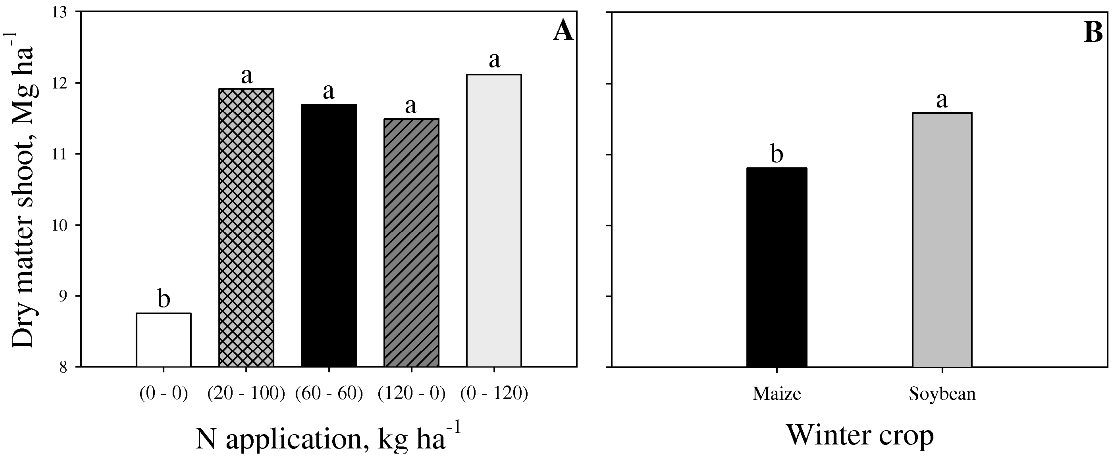

Figure 2. Dry matter production of maize shoots in terms of the N application strategies (A) and winter crops (B). (Different letters indicate a difference as indicated by Tukey's test at 5%; On the X axis of item A, the first number corresponds to the rate of N applied at preplanting, and the second to the rate applied in the top dressing).

Similarly, the maize grain yield was significantly greater when the preceding crop was soybeans. However, this difference was only observed when there was no N application. When N fertilization was performed, the yield was greater than that observed in the control (without N), and significant differences were not observed in terms of the winter crop (Figure 3B).

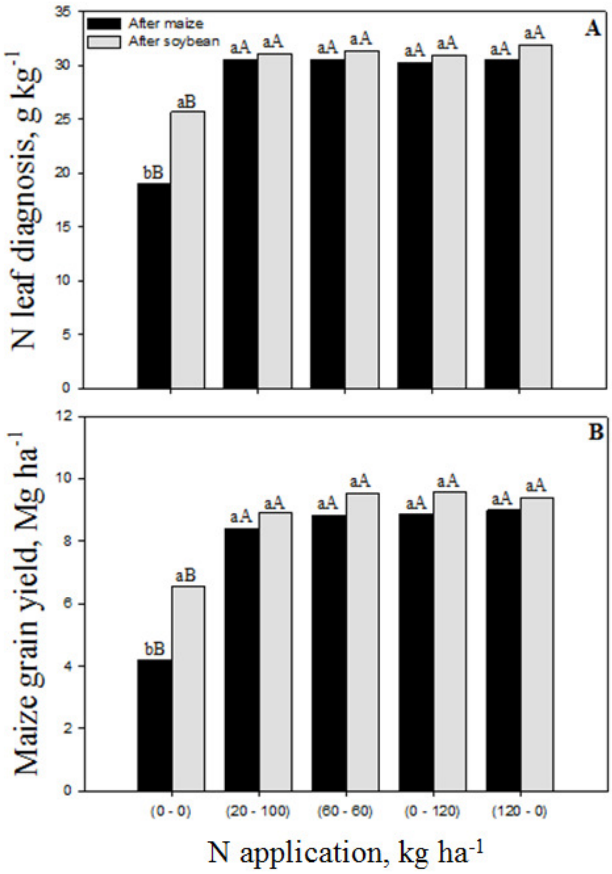

Figure 3. Nitrogen concentrations from the leaf diagnosis (A) and maize grain yield (B) in relation to the N application strategies and winter crops. The small letters indicate differences (Tukey's test at 5%) between the winter crops within each fertilization strategy and capital letters indicate differences (Tukey's test at 5%) between the N application strategies. On the X axis, the first number corresponds to the rate of N applied at preplanting, and the second to the rate applied in the top dressing.

The beneficial effects of N fertilization on dry matter production, on the concentration of this nutrient in the plant and, especially, on maize grain yield have been observed by various authors (BASSO; CERETTA, 2000; AITA et al., 2001; OHLAND et al., 2005; SILVA et al., 2005; STRIEDER et al., 2006; SORATTO et al., 2011). The N supply may alter the characteristics of the root system (JENKINSON et al., 1985; KRISTENSEN; THORUP-KRISTENSEN, 2007) and lead to an increase in the leaf area (VALENTINUZ; TOLLENAAR, 2006), bearing in mind that this element influences photosynthetic processes and the production of the phytohormones responsible for cell division and expansion (MENGEL; KIRKBY, 2001). This sequence of actions has a positive influence on the maize yield components, particularly on the number of kernels per ear, which increases the crop yield (SILVA et al., 2005; SORATTO et al., 2011).

Plants grown after maize that did not receive any N were visibly shorter and had a smaller stalk diameter, smaller leaves and a pale green coloration. The leaf diagnosis revealed that these plants had N concentrations of approximately 19.0 g kg^{-1}. Despite having a lower yield than the treatments that received N fertilizer, the plants grown without N and following soybeans did not have these N deficiency symptoms, with the leaf diagnosis revealing a concentration of approximately 25.7 g kg^{-1} N. In both cases, the concentrations were below the lower limit (27 g kg^{-1} N) of the range considered adequate by Cantarella et al. (1996).

The average yield of the treatments that received N applications was 9,058 kg ha^{-1} grain, and the plants from these treatments had mean leaf N concentrations of 31 g kg^{-1}. Considering this average yield, the N applications provided for a 116% increase in the grain yield compared with maize growing in the absence of N fertilization and following maize. When soybeans were used as the winter crop, N applications increased the maize yield by 38%. In the control areas (without added N), the maize yield following soybeans was 57% greater than that obtained in the maize following maize.

The observation that the maize grown after soybeans had greater N concentrations in the leaf diagnosis (Figure 3A) and consequently greater dry matter production (Figure 1) and grain yields (Figure 3B) is likely related to the greater supply of N provided by this legume. With a lower C/N ratio than maize, soybean residues are more rapidly mineralized, and therefore, the N undergoes less immobilization by soil microorganisms during organic matter decomposition, which makes N more available to the subsequent crop. Basso e Ceretta (2000) also observed that there was a tendency for greater maize N uptake when grown after a leguminous plant (combination of common vetch + black oats), particularly in the absence of N fertilization, as reflected in the grain yield of the crop. AITA et al. (2001) observed that in the absence of N fertilization, the average grain yield of maize following leguminous plants was greater by 89% and 43% than those obtained in the treatments with black oats and winter fallow, respectively.

These results showed that the preceding crop must be considered for the correct N fertilization management. In this respect, specifically for maize after soybeans, Bundy et al. (1993), Ding et al. (1998) and Varvel e Wilhelm (2003) observed that maize obtained 50, 45 and 65 kg ha^{-1} N, respectively, on average from the soybean crop. Nevertheless, it is important to note that the N contributions provided by the preceding crop and their utilization by the following crop varied in terms of the crop year, region, soil and crop management.

The absence of significant fertilization strategy effects (with the exception of treatments without N applications) on the N concentrations from the leaf diagnosis (Figure 3A), dry matter production (Figure 2A) and grain yield (Figure 3B) may be explained by the initial available N soil content, which was sufficient for meeting the plant demand for this nutrient, at least until the second application of N, including when the preceding crop was maize. As a consequence of the high C/N ratio of the maize residue, there may have been greater N organic material immobilization by decomposing microorganisms compared with the soybean residue. Nevertheless, this N immobilization did not hurt the initial development of the plants (up to the V4 – V5 stage). Thus, whether the application of the whole N portion occurred at preplanting, split application or completely at the top dressing was irrelevant.

In dealing with an area that has been under the no-tillage system for several years, the processes that govern the N dynamic in the soil-plant system acquire a certain balance, which raises the availability of this nutrient to plants compared with that during the first years following adoption (SIQUEIRA NETO et al., 2010). Studies that used fertilizers labeled with ^{15}N showed that even after performing N fertilization, most of the N taken up by maize during its cycle was derived from the soil, indicating that a considerable quantity of the N from the fertilizer likely remains in the soil (SILVA et al., 2006). This distribution occurs because the native mineral N in the soil is substituted by the applied mineral N, which is known as “pool substitution” (JENKINSON et al., 1985; RAO et al., 1992). Silva et al. (2006) observed that the quantity of native N from the soil contained in the maize plants was more than double the quantity derived from the inorganic fertilizer.

Nitrogen application at preplanting has proven to be an alternative to optimizing machinery use on the property, particularly on soils with a considerable clay content and under a consolidated no-tillage system. Thus, as observed in this experiment, Pötteker e Wiethölter (2000) showed that there were no significant differences in the maize grain yield in terms of N application at preplanting (ten days before planting), planting and planting + top dressing in a year with regular rainfall in Oxisol under a no-tillage system. Wolschick et al. (2003) reported that the maize yield was not significantly affected by different fertilization times, even with high rainfall. Sá (1996) similarly observed that N application at preplanting was advantageous even with 330 mm of rainfall occurring from preplanting fertilization until maize planting.

In contrast, Basso e Ceretta (2000) and Pötteker e Wiethölter (2000) observed yield reductions when the fertilization was performed at preplanting during years with high rainfall, and they attributed this effect to greater nitrate leaching losses. In the present study, the rainfall occurring from the time of N application at preplanting until the maize plants had four to five completely unrolled leaves was 173.7 mm.

CONCLUSION

Maize grown after soybeans had both greater N concentrations and production (dry matter and grain) relative to the maize grown after maize.

Applying the whole quantity of N at preplanting, in the top dressing or in a split application did not lead to significant differences in the N concentration (plant and leaf diagnosis) or in the production (shoot dry matter and grain).

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RESUMO: O aproveitamento do N pelo milho cultivado em sistema plantio direto é dependente da qualidade dos resíduos da cultura antecessora, que por sua vez podem promover diferenças na eficiência da adubação nitrogenada em função da época em que esta é realizada. Assim, objetivou-se avaliar o estado nutricional e as produções de massa seca e grãos do milho cultivado em um Latossolo Vermelho eutroférrico argiloso sob plantio direto. Adotou-se o delineamento em blocos casualizados com parcelas subdivididas, com três repetições. As parcelas corresponderam às estratégias de aplicação de N e as subparcelas às culturas de entressafra (soja e milho). As estratégias de adubação (dose: 120 kg ha^{-1} de N) foram: (0 – 0), (20 – 100), (60 – 60), (120 – 0) e (0 – 120), onde o primeiro número corresponde à dose de N (kg ha^{-1}) aplicada em pré-semeadura e o segundo à dose aplicada em cobertura (estádio V4-5). A adubação nitrogenada elevou os teores de N na parte aérea e na folha diagnose e, consequentemente, as produtividades de massa seca e grãos de milho. Na ausência da aplicação de N, o milho em sucessão a soja apresentou concentrações superiores de N na parte aérea e na folha diagnose e maiores produtividades de massa seca da parte aérea e de grãos em relação à sucessão milho-milho. Ao se aplicar a dose de 120 kg ha^{-1} de N, as estratégias de aplicação desse nutriente não influenciaram significativamente as variáveis avaliadas, independentemente da cultura de entressafra.

PALAVRAS-CHAVE: Parcelamento de nitrogênio. Adubação de pré-semeadura. Solo tropical. Soja. *Zea mays*.

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