Maize nitrogen fertilization in two crop rotation systems under no-till[1]

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ABSTRACT

The objective of this study was to evaluate split nitrogen (N) fertilization of maize applied in band at sowing and top dressing with and without crop rotation, under no-till. The experiment was conducted with six N rates at sowing (0, 20, 30, 40, 50 and 60 kg ha^{-1}) combined with three rates in top dressing (40, 70, 100 kg ha^{-1}) and two management systems: after five cropping sequences of maize and crop rotation (maize + soybean + oat + soybean + corn) in a randomized block design with four replications. The crop rotation system increased yield in approximately 7% in relation to the area without rotation. The split of nitrogen fertilization, in rates above 39 and 54 kg ha^{-1} at sowing and 70 and 40 kg ha^{-1} in top dressing, resulted in yield higher than that obtained with the application of 100 kg ha^{-1} in top dressing. Grain yield was higher with the rates 50 and 70 kg ha^{-1} of N compared with that obtained with 20 and 100 kg ha^{-1} at sowing and top dressing, respectively. The rate 70 kg ha^{-1} of N resulted in the highest yield at the lowest cost compared with the revenues and costs incurred with the rates 40 and 100 kg ha^{-1}.

Key words: fertilization, soil management, *Zea mays* L., yield.

RESUMO

Adubação nitrogenada para o milho em dois sistemas de rotação de culturas sob plantio direto

Com o objetivo de avaliar o parcelamento de doses de nitrogênio (N), aplicadas na semeadura e em cobertura do milho, com e sem rotação de culturas, em semeadura direta, foi realizado um experimento com seis doses de N na semeadura (0, 20, 30, 40, 50 e 60 kg ha^{-1}), combinadas com três doses em cobertura (40, 70, 100 kg ha^{-1}) e dois sistemas de manejo: após cinco cultivos de milho e com rotação de culturas (milho+soja+aveia+soja+milho), em delineamento de blocos casualizados, com quatro repetições. O sistema de rotação de culturas proporcionou incremento de aproximadamente 7%, no rendimento de grãos, em relação ao da área sem rotação. O parcelamento da adubação nitrogenada, com doses acima de 39 e 54 kg ha^{-1}, na semeadura, com 70 e 40 kg ha^{-1}, em cobertura, respectivamente, resultou em produtividade superior à obtida com aplicação de 100 kg ha^{-1}, em cobertura. O rendimento de grãos foi maior com o parcelamento da dose de 50 e 70 kg ha^{-1} de N, na semeadura e cobertura, em comparação com o obtido com o parcelamento de 20 e 100 kg ha^{-1}, na semeadura e cobertura, respectivamente. A dose de 70 kg ha^{-1} de N em cobertura apresentou maior produtividade de grãos com menor custo, em comparação com os rendimentos e custos verificados em relação às doses de 40 e 100 kg ha^{-1}.

Palavras-chave: fertilização, manejo do solo, *Zea mays* L., produtividade.

Received: 27/03/2013; Accepted: 28/05/2013.

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INTRODUCTION

Maize (*Zea mays* L.) is one of the main cereal crops grown in Brazil and worldwide (CONAB, 2012). The world maize production reached 905 million tons and is destined mainly for animal feed and ethanol production. In the United States of America (US), the annual production reaches 336 million tons (USDA, 2012), while Brazil produces about 68 million tons (CONAB, 2012).

In the 2011/2012 crop year, the mean grain yield of the maize crop in Brazil was around 4400 kg ha^{-1} (CONAB, 2012), which is considered low when compared with the US yield of 9240 kg ha^{-1} (USDA, 2012). Among the factors accounting for the high yield of the maize crop in the US is the expressive use of nitrogen fertilizers. The Brazilian low yield is related to soil fertility, climatic conditions (Chioderoli *et al*., 2012) and insufficient nitrogen (N) fertilization (Silva *et al*., 2006). Therefore, the rational and balanced use of fertilizers, which represent a large part of the crop establishment costs, has been gaining an increasing importance for financial gain (Amado *et al*., 2002).

The split and time of nitrogen application are alternatives to increase the efficiency of fertilizers and minimize losses, allowing for synchronization between the applications and the period of high nutrient demand (Yamada *et al*., 2006). Other factors that influence the recommended rate and split of fertilization are the chemical attributes, such as the content of soil organic matter (SOM) and the weather, primarily the rainfall (Chioderoli *et al*., 2012).

High yields were recorded for rainfed maize fertilized with 50-90 kg ha^{-1} N and irrigated maize fertilized with 120-150 kg ha^{-1} (Souza *et al*., 2003), reaching yields above 150 kg ha^{-1} (Amado *et al*., 2002), also with good response in association with brachiaria (Costa *et al*., 2012).

The no-till (NT) system with crop rotation has provided maize yields higher than other cropping systems. In this system, there is an increased amount of potentially mineralizable nitrogen (PMN) in the soil, because of the residues remaining on the ground (Silva *et al*., 2005), especially in areas where the use of this system is already consolidated (Gomes *et al*., 2007). However, this will depend on the degree of SOM decomposition, the time of NT adoption (adoption phase, transition, consolidation or of maintenance) (Anghinoni, 2007) and quality of straw decomposition (Cabezas *et al*., 2005).

The contribution of cover crops to N supply and the crop rotation of maize plus soybean are important practices that contribute to the increase of N content in the soil (Jantalia *et al*., 2006). Cover crops can meet the demands for N of maize by using rotation with legume crops. However, when using species with high C/N ratio, such as grasses, cereal yield can be reduced if there is insufficient N complementation, via fertilization (Lara-Cabezas *et al*., 2004).

For these reasons, in order to evaluate nitrogen management, this study evaluated the split N fertilization and the influence of the crop rotation system on agronomic characteristics, grain yield and N, P and K contents in the leaf tissue of maize.

MATERIAL AND METHODS

The field experiment was conducted in no-till system, in place for six years (transition phase), in the municipality of Marechal Cândido Rondon, western Paraná, with geographic coordinates 24º 42' S and 54º 14', approximately 220 m altitude, average annual rainfall of 1642 mm, average temperature of 21.3 ºC and average relative humidity of 76.1% (IAPAR, 2011). The soil of the experimental area is classified as typical Eutroferric Red Latosol (LVef) (Embrapa, 2006b).

Before the implementation of the experiment, soil samples at 0-0.2 m were collected for determination of chemical and particle size analyses, at the sites 1 and 2 respectively. The results of the soil analyses were: pH $CaCl_2$ = 5.5 and 5.2, MO = 29.4 and 29.4 g dm^{-3}; P = 7.6 and 5.12 mg dm^{-3}; H + Al: 34 and 50 $mmol_c$ dm^{-3}; Al^{3+}: 0 and 0.1 $mmol_c$ dm^{-3}; K^+ = 6.0 and 3.3 $mmol_c$ dm^{-3}; Ca^{2+} = 42.2 and 41.8 $mmol_c$ dm^{-3}; Mg^{2+} = 15.5 and 13.8 $mmol_c$ dm^{-3}; SB = 64 and 59 $mmol_c$ dm^{-3}; CTC = 98 and 108 $mmol_c$ dm^{-3}; V = 64.8 and 54.3%; and sand, silt and clay 110 , 120 and 770 g dm^{-3}, respectively.

The experiment consisted of 36 treatments arranged in a 6 x 3 x 2 factorial randomized block design, with four replications. We evaluated the combination of six N rates (0, 20, 30, 40, 50 and 60 ha^{-1}) at sowing, three N rates (40, 70 and 100 kg ha^{-1}) in topdressing and two rotation systems in no-till. The rotation system at Site 1 consisted of five cropping sequences of maize and, at Site 2, of crop rotation (corn + soybean + oats + soybean + corn), totaling 144 experimental units. Before the establishment of the experiment, soil acidity was corrected by lime (TNP – total neutralizing power – 85%) distribution on the surface of the two sites, without incorporation, to increase the saturation to 70%.

The experiment was conducted in the crop year 2006/2007 using maize seeds of the single early hybrid Dow AgroSciences 2B710. Furrows were opened for N fertilizer placement at sowing. Phosphorus (P) and potassium (K) fertilization rates were 75 and 50 kg ha^{-1} of P2O5 and K2O, respectively, in both sites using triple superphosphate (44% P_2O_5) and potassium chloride (60% K_2O).

Urea (45% N) was used as N source for band fertilization at sowing and topdressing. N topdressing was carried out when the maize plants had five expanded leaves (V5), by broadcasting over the entire area of the plot. Each experimental unit consisted of five rows (6 m long) spaced 0.70 m apart. Three central rows of each plot were harvested for evaluations, eliminating 0.5 m from each end.

The following variables were evaluated: grain yield, 1000-grain mass, N content in the grain, N, P and K in leaf tissue, plant height, height of ear insertion, stem diameter, row number per ear, grain number per row, grain number per ear, ear length and relative price between product (grain) and fertilizer. To obtain this ratio, we used the maize closing price on the Chicago Board of Trade (CBOT) of March 2013 for the region, which was R$ 24.50 per 60-kg bag (CBOT, 2013), and R$ 1.18 per kg of N for urea. The ratio was calculated using the following equation: RPR = [(PT x R$ kg) / (kg urea-N x R$ kg urea-N)], where: RPR = relative price in Real; PT = treatment production (kg); R$kg = Real kg^{-1} maize; kg urea-N = N amount used (kg); R$ kg N-urea = Real kg^{-1} N-urea. The increase in production of each treatment was calculated considering the production obtained with the lowest N rate, as follows: {[production per treatment / production obtained with the lowest N rate] x 100}.

Analysis of variance and regression analysis were performed using the software SAEG 8.0 (SAEG, 1999). Treatments with the same N rate were compared by contrasts using the Bonferroni test, at 1 and 5% significance.

RESULTS AND DISCUSSION

Maize yield was significantly different between the sites with a positive interaction between N band fertilization at sowing and topdressing (Table 1). The area with crop rotation (Site 2) had higher mean yield, greater ear length and higher 1000-grain mass than the area with successive maize (Site 1). There was significant effect of N fertilization at sowing for almost all variables, except for height of ear insertion and row number per ear.

The interaction between N rate at sowing and N rate in topdressing (with 40 and 70 kg ha^{-1} N) showed an increase in yield of 24.82 and 26.76 kg ha^{-1} grain, respectively, for each kg of N applied at planting (Figure 1a). The rates 40 and 70 kg ha^{-1} in topdressing with N at sowing above 54 and 39 kg ha^{-1}, respectively, resulted in production larger than the mean production obtained with 100 kg ha^{-1} in topdressing, which was 8864 kg ha^{-1} (Figure 1a).

The increase in production with the use of higher N rates at sowing, in comparison with those commonly used (20 to 30 kg N ha^{-1}), indicate less need for N in topdressing, allowing high yields (Embrapa , 2006a). However, care must be taken with N rates above 60 kg ha^{-1} at sowing, which may favor salinity and/or alkalinization of the rhizosphere, damaging the plant root system and reducing the rate of nutrient absorption (Fancelli & Dourado Neto, 2004).

There were differences between N rates at sowing for plant height, but not for height of ear insertion, for any of the rates evaluated at sowing and topdressing (Table 1). Lana *et al*. (2009) observed increased plant height and height of ear insertion, 2.1cm and 1.8 cm, respectively, per 30 kg of N added.

Figure 1b shows the mean yield of the two sites, with total rates of N, independent of the application form. It was possible to fit a quadratic equation with the maximum point of 132.4 kg N ha^{-1} and grain yield of 9038 kg ha^{-1}, which was also reported by Gomes *et al*. (2007), with a maximum point of 151 kg ha^{-1} N.

This total N rate is lower than that recommended by Embrapa (2006a), which for an expected yield above 8000 kg ha^{-1}, recommends 20 to 30 kg ha^{-1} at sowing and 140 kg ha^{-1} in topdressing. This may be explained by the significant amount of crop residues in both areas, which may be releasing N through SOM mineralization, especially in the system of rotation with soybean. Araújo *et al*. (2004) have also reported linear responses of increased yield as a function of maize nitrogen fertilization in an Oxisol and Costa *et al*. (2012) in an intercropping with brachiaria.

For most N rates evaluated, with exception of the treatments 40 kg ha^{-1} N at sowing and 100 kg ha^{-1} N in topdressing, the site with crop rotation had higher yields than the site with successive maize crops. The differences between the systems ranged from 38 kg ha^{-1} to 1468 kg ha^{-1} of grain produced in the treatments with 50 kg ha^{-1} N at sowing and 70 kg ha^{-1} N in topdressing and 60 kg ha^{-1} N at sowing and 70 kg ha^{-1} N in topdressing, respectively (Table 2).

The importance of the N fertilization at sowing for corn yield is confirmed when comparing the results of the application of 30 kg N ha^{-1} at sowing plus 40 kg ha^{-1} N in topdressing with the application of 70 kg N ha^{-1} only in topdressing (Table 2). In this case, there is an increase in yield of 590 and 428 kg ha^{-1} for the sites 1 and 2, respectively. The same happens with the rates 50-70 kg ha^{-1} compared with 20-100 kg N ha^{-1}, and 50-40 kg ha^{-1} compared with 20-70 kg ha^{-1} N at sowing and in topdressing, respectively. These results may be due to the greater efficiency of N utilization, with small losses by volatilization compared to losses with surface applications at higher rates (Yamada *et al*., 2006).

Silva *et al*. (2006) obtained better results with up to half of the rates applied at sowing (60 kg ha^{-1}) and the remaining in topdressing, from stages V4 to V6. Cabezas *et al*. (2005) agree with the rates 30 to 40 kg ha^{-1} of N at sowing in the early years of NT adoption, reducing and/or eliminating the initial N deficiency, because of the immobilization caused by the decomposition of antecedent crop residues. The highest yield among treatments was recorded for the rates 60 kg ha^{-1} at sowing and 70 kg ha^{-1} in topdressing for site 2, reaching 9970 kg ha^{-1} (Table 2). Araújo *et al*. (2004) reported yield of 11,203 kg ha^{-1} by applying 240 kg N ha^{-1} in topdressing split four times, at the stages V4, V8, V12 and bolting.

Table 1. Summary of analysis of variance and mean comparisons for yield, N content in leaf and grain, leaf P, leaf K, height of ear insertion, plant height, stem diameter, ear length, row number per ear, grain number per row, grain number per ear and 1000 grain mass in response to nitrogen fertilization at sowing and topdressing in two sites

Analysis of variance	Yield	Leaf N	Grain N	Leaf P	Leaf K	Height of ear insertion	Plant height	Stem diameter	Ear length	Row number per ear	Grain number per row	Grain number per ear	1000 grain mass
	kg ha^{-1}	g kg^{-1}				m		mm	cm				g
40 ha^{-1} N Topd.	8,374b	24.12c	11.15c	2.64b	20.94a	0.95a	2.30a	16.13a	16.08a	18.71a	31.59a	590.89a	259.3a
70 ha^{-1} N Topd.	8,792a	25.19b	11.55b	2.79a	20.69a	0.95a	2.31a	16.10a	16.31a	18.64a	31.62a	589.39a	266.4a
100 kg ha^{-1} N Topd.	8,964a	26.04a	11.94a	2.82a	20.62a	0.95a	2.31a	16.31a	16.41a	18.71a	33.84a	632.25a	264ab
0 kg ha^{-1} N Sow.	7903	24.79	11.11	2.82	23.74	0.93	2.24	16.05	15.43	18.39	29.99	551.41	257.55
20 kg ha^{-1} N Sow.	8485	23.92	11.14	2.63	19.94	0.96	2.31	15.71	16.11	18.62	31.83	592.44	255.52
30 kg ha^{-1} N Sow.	8814	25.45	11.41	2.70	20.27	0.96	2.31	16.11	16.52	18.61	34.69	645.36	264.66
40 kg ha^{-1} N Sow.	8840	24.97	11.58	2.73	20.10	0.94	2.32	16.12	16.25	18.71	31.88	596.52	264.75
50 kg ha^{-1} N Sow.	8900	25.99	11.83	2.75	20.16	0.95	2.33	16.47	16.60	18.85	32.76	617.38	264.27
60 kg ha^{-1} N Sow.	9118	26.25	12.18	2.86	20.29	0.95	2.32	16.63	16.70	18.94	32.22	609.70	272.57
Site 1	8388b	25.35a	11.67a	2.86a	20.60a	0.95a	2.30a	16.20a	16.01b	18.82a	31.69a	596.46a	259.22b
Site 2	8965a	24.88a	11.42b	2.64b	20.90a	0.95a	2.31a	16.17a	16.52a	18.55b	32.77a	607.81a	267.22a
F value													
Site	34.74 **	3.06 ^{NS}	13.3 **	51.7 **	0.91 ^{NS}	1.04 ^{NS}	0.56 ^{NS}	0.06 ^{NS}	14.71 **	5.20 *	1.96 ^{NS}	0.6 ^{NS}	14.84 **
Fert. Sow.	12.96 **	6.72 **	24.8 **	5.01 **	15.4 **	0.89 ^{NS}	7.94 **	3.49 **	8.17 **	1.90 ^{NS}	2.54 *	2.93 *	5.71 **
Fert. Topd.	7.92 **	19.01**	36.8**	14.3 **	0.09 ^{NS}	0.89 ^{NS}	0.61 ^{NS}	0.94 ^{NS}	1.87 ^{NS}	0.04 ^{NS}	2.51 ^{NS}	2.52 ^{NS}	4.15 *
Fert. Sow. x Topd.	2.10 *	1.50 ^{NS}	1.02 ^{NS}	1.96 *	1.07 ^{NS}	1.26 ^{NS}	0.82 ^{NS}	0.73 ^{NS}	1.08 ^{NS}	0.86 ^{NS}	0.75 ^{NS}	0.60 ^{NS}	0.81 ^{NS}
Topdress x Site	1.05 ^{NS}	0.50 ^{NS}	4.74 *	0.42 ^{NS}	0.15 ^{NS}	0.64 ^{NS}	0.09 ^{NS}	1.96 ^{NS}	1.6 ^{NS}	1.55 ^{NS}	1.33 ^{NS}	2.14 ^{NS}	4.58 *
At sowing x Site	1.61 ^{NS}	0.64 ^{NS}	3.29 **	0.40 ^{NS}	1.46 ^{NS}	2.27 ^{NS}	0.89 ^{NS}	1.01 ^{NS}	2.89 **	0.91 ^{NS}	1.37 ^{NS}	1.28 ^{NS}	3.14 *
Topd. x Sow. x Site	1.07 ^{NS}	1.03 ^{NS}	0.69 ^{NS}	0.44 ^{NS}	1.85 ^{NS}	0.89 ^{NS}	0.97^{NS}	0.59^{NS}	0.74 ^{NS}	0.58 ^{NS}	0.87 ^{NS}	0.82 ^{NS}	1.22 ^{NS}
CV (%)	6.8	6.4	3.6	6.6	8.9	4.8	2.5	5.2	4.9	3.7	14.3	14.6	4.7

Means followed by the same letters in the columns are not significantly different by the Tukey test at 5% probability level; ^{NS}: not significant, * significant at 5%, ** significant at 1% probability level by the F test.

The mean yield of Site 2 was 577 kg ha^{-1} higher than the mean yield of Site 1, i.e., increasing from 8388 kg ha^{-1} to 8965 kg ha^{-1} grain (Table 2). There were yield increases in relation to the lowest N rate, ranging from 6.8% for the treatment 0 kg ha^{-1} at sowing and 70 kg ha^{-1} in topdressing to 25.8% for the treatment 60 kg ha^{-1} at sowing and 70 kg ha^{-1} in topdressing. Similar increases in production were also reported by Araújo *et al*. (2004) in monoculture systems (maize+ maize + maize and maize + soybean + maize).

The economic analysis also has shown that grain yield per kilogram of applied N was satisfactory, providing a good return on capital invested in the form of nitrogen fertilizer. Investment in nitrogen fertilizer was positive for all treatments, with average return of R$ 30.88 and R$ 33.21 for every R$ 1.00 invested in nitrogen fertilizer, for sites 1 and 2, respectively, representing an average gain of R$ 32.04 in grains per Real of N invested (Table 2). The rate 70 kg ha^{-1} in topdressing combined with 30 and 50 kg ha^{-1} at sowing also provided larger increases in production. Farinelli & Lemos (2012) reported that the nitrogen fertilization provided significant increases in agronomic and nutritional traits of maize, with the maximum grain yield obtained with 151 kg ha^{-1} N.

Table 3 shows the comparisons between the rates of N in topdressing (C1, C2 and C3) and comparisons involving the split of nitrogen fertilization at the rates 70 (C4), 90 (C5), 100 (C6, C7 and C8), 120 (C9) and 130 (C10) ha^{-1} of total applied N. Maize yield was higher for the topdressing N rates 70 and 100 kg ha^{-1} N than the yield obtained with 40 kg ha^{-1} N. However, the yields at 70 and 100 kg ha^{-1} were not significantly different; therefore the best topdressing rate was 70 kg ha^{-1} N.

The fourth contrast shows that there were differences by splitting the rate 70 kg N ha^{-1}, indicating that splitting the rate into 30 kg ha^{-1} N at sowing and 40 kg ha^{-1} N in topdressing, the maize yield increased in 509 kg ha^{-1} (Table 3). The same

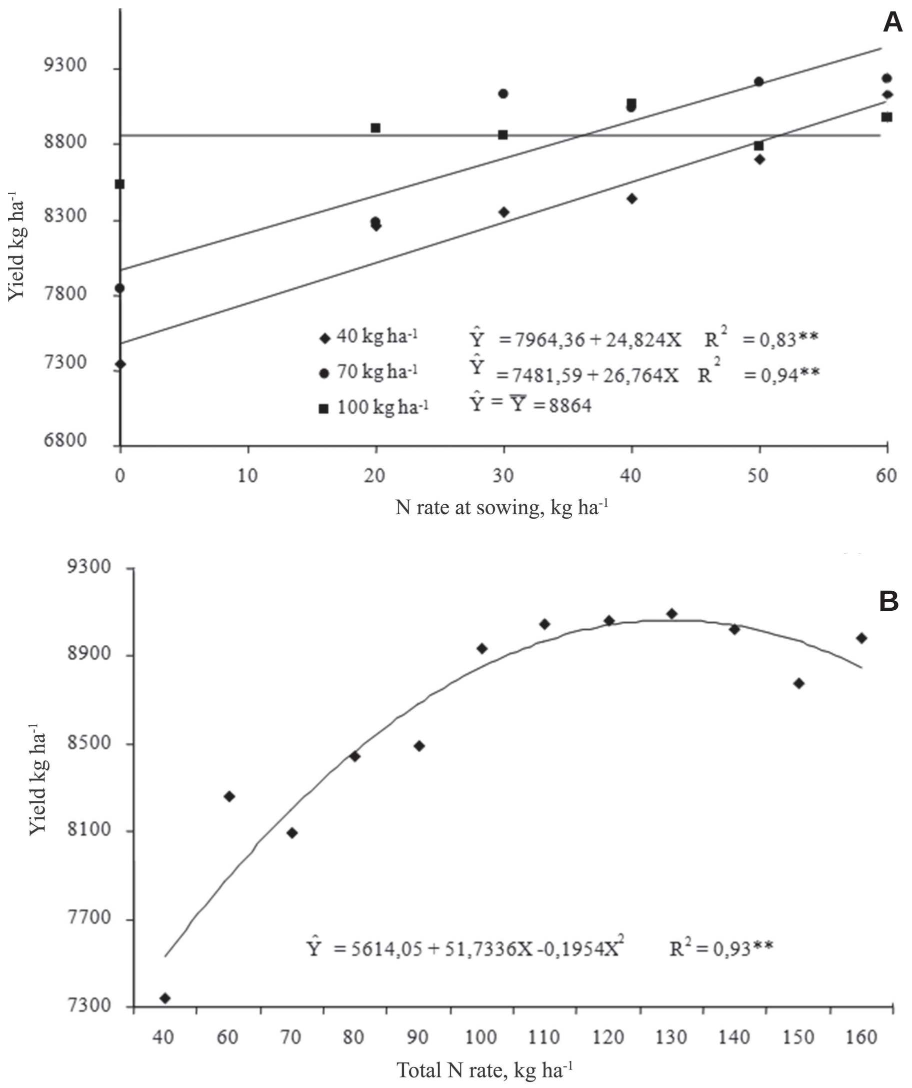

Figure 1. Mean yield of maize from two sites as a function of N rate at sowing (A) and total N rate applied at sowing and topdressing (B).

trend was observed for the rate 90 kg ha^{-1}, with significant difference for the splitting form in contrast 5, showing that the increase in the N rate at sowing to 50 kg ha^{-1} resulted in an increase of 426 kg ha^{-1} of grains compared with that obtained by the addition of 20 kg ha^{-1} of N at sowing .

The contrasts 6, 7 and 8 provided comparisons between the splitting forms of the rate 100 kg ha^{-1} N. Estimates of the contrasts 6 and 7 emphasize again the importance of N fertilization at sowing, because when the fertilizer was applied in topdressing only, there was a

Table 2. N rates at sowing (S) and topdressing (C) and respective maize yields, relative price between maize production and nitrogen fertilizer and the average increase in yield in relation to the lowest fertilizer rate

Treatment	Yield			Prices[1]			Yield increase
	Site 1	Site 2	Mean	Site 1	Site 2	Mean	
	kg ha^{-1}			R$ of maize/R$ of urea			%
T1 = $S_0 + C_{40}$	6779	7900	7340	58.64	68.34	63.49	
T2 = $S_0 + C_{70}$	7600	8080	7840	37.57	39.94	38.75	6.8
T3 = $S_0 + C_{100}$	7865	9196	8531	27.21	31.82	29.52	16.2
T4 = $S_{20} + C_{40}$	7979	8547	8263	46.01	49.29	47.65	12.6
T5 = $S_{20} + C_{70}$	7991	8570	8281	30.72	32.95	31.83	12.8
T6 = $S_{20} + C_{100}$	8559	9263	8911	24.68	26.71	25.69	21.4
T7 = $S_{30} + C_{40}$	8190	8508	8349	40.48	42.06	41.27	13.7
T8 = $S_{30} + C_{70}$	8639	9633	9136	29.89	33.33	31.61	24.5
T9 = $S_{30} + C_{100}$	8927	8987	8957	23.76	23.92	23.84	22.0
T10 = $S_{40} + C_{40}$	8353	8538	8445	36.13	36.93	36.53	15.1
T11 = $S_{40} + C_{70}$	8469	9625	9047	26.64	30.31	28.47	23.3
T12 = $S_{40} + C_{100}$	9062	8991	9026	22.40	22.22	22.31	23.0
T13 = $S_{50} + C_{40}$	8628	8787	8707	33.17	33.78	33.48	18.6
T14 = $S_{50} + C_{70}$	9192	9230	9211	26.50	26.61	26.56	25.5
T15 = $S_{50} + C_{100}$	8668	8888	8778	20.00	20.50	20.25	19.6
T16 = $S_{60} + C_{40}$	8772	9505	9138	30.35	32.89	31.62	24.5
T17 = $S_{60} + C_{70}$	8502	9970	9236	22.63	26.54	24.58	25.8
T18 = $S_{60} + C_{100}$	8812	9149	8980	19.06	19.79	19.42	22.3
Mean	8388	8965	8676	30.88	33.21	32.04	19.3

Site 1: area with five cropping sequences of maize; Site 2: area with crop rotation (maize+soybean+oat+soybean+maize). [1]Maize price, quotation from January 2013 = R$ 24.50 bag; Urea price (kg ha^{-1}) = R$ 1.18 kg.

Table 3. Contrast estimates and significance tests for maize yield as a function of nitrogen fertilization at sowing (S) and topdressing (C)

Contrast	Treatments	Estimates
	Comparison between N rates in topdress	kg ha^{-1}
C_1: C_{40} vs C_{70}	$(T_1+T_4+T_7+T_{10}+T_{13}+T_{16})$ - $(T_2+T_5+T_8+T_{11}+T_{14}+T_{17})$	- 418**
C_2: C_{40} vs C_{100}	$(T_1+T_4+T_7+T_{10}+T_{13}+T_{16})$ - $(T_3+T_6+T_9+T_{12}+T_{15}+T_{18})$	- 479**
C_3: C_{70} vs C_{100}	$(T_2+T_5+T_8+T_{11}+T_{14}+T_{17})$ - $(T_3+T_6+T_9+T_{12}+T_{15}+T_{18})$	- 61^{ns}
	Comparison between 70 N	
C_4: $(S_0 + C_{70})$ vs $(S_{30} + C_{40})$	$T_2 - T_7$	-509**
	Comparison between 90 N	
C_5: $(S_{20} + C_{70})$ vs $(S_{50} + C_{40})$	$T_5 - T_{13}$	-426**
	Comparison between 100 N	
C_6: $(S_0 + C_{100})$ vs $(S_{30} + C_{70})$	$T_3 - T_8$	-605**
C_7: $(S_0 + C_{100})$ vs $(S_{60} + C_{40})$	$T_3 - T_{16}$	-607**
C_8: $(S_{30} + C_{70})$ vs $(S_{60} + C_{40})$	$T_8 - T_{16}$	-2^{ns}
	Comparison between 120 N	
C_9: $(S_{20} + C_{100})$ vs $(S_{50} + C_{70})$	$T_6 - T_{14}$	-300*
	Comparison between 130 N	
C_{10}: $(S_{30} + C_{100})$ vs $(S_{60} + C_{70})$	$T_9 - T_{17}$	-279^{ns}

**, * Significant at 1 and 5% by the Bonferroni test; ns = non-significant at 5% probability test by the Bonferroni test.

reduction of 605 and 607 kg ha^{-1} in the maize production, respectively, i.e., a significant reduction in yield.

The contrast established for maize production with the rate 120 kg N ha^{-1} (C9), indicated that the best splitting form was the application of 50 kg ha^{-1} of N at sowing and 70 kg ha^{-1} N in topdressing. There was an increase of 300 kg ha^{-1} in grain production compared with that obtained from the management commonly used in various maize production regions, which is 20 kg ha^{-1} N at sowing and 100 kg ha^{-1} N in topdressing. No yield differences were found for the split of the rate 130 kg N ha^{-1} (C10). Fancelli & Dourado Neto (2002) stated that a high input of N at sowing provides larger number of grains per ear and allow greater flexibility in the period of topdress application of nitrogen, which can be extended to the stages V7 and V8.

Site 1 had, on average, larger 1000-grain mass than Site 2, which reflected in the yield (Figure 2a). There was an increase of 0.045 g per kg ha^{-1} of N applied at sowing (linear increase) in the Site 1, but no differences were found for the rates of N applied at sowing in Site 2. This trend of grain mass increase was also reported by Lana *et al*. (2009), but different from that reported by Gomes *et al*. (2007).

The conflicting results in the literature show that the grain mass is a trait not only influenced by nutrient availability, but is also influenced by genotype and climatic conditions of the region. This behavior is probably a result of soil management, which in case of Site 2, there may be a better balance between mineralization and immobilization of N. Thus, over the years, when the no-till system is consolidated, it will be possible to reduce fertilizer rates (Anghinoni, 2007), as the effect of increased biomass production and, consequently, the increase of carbon stocks and N in the soil.

There was an increase in N content of grains with increasing N rates at sowing for both sites. In Site 1, the N content increased from the rate 15 kg ha^{-1} N at sowing

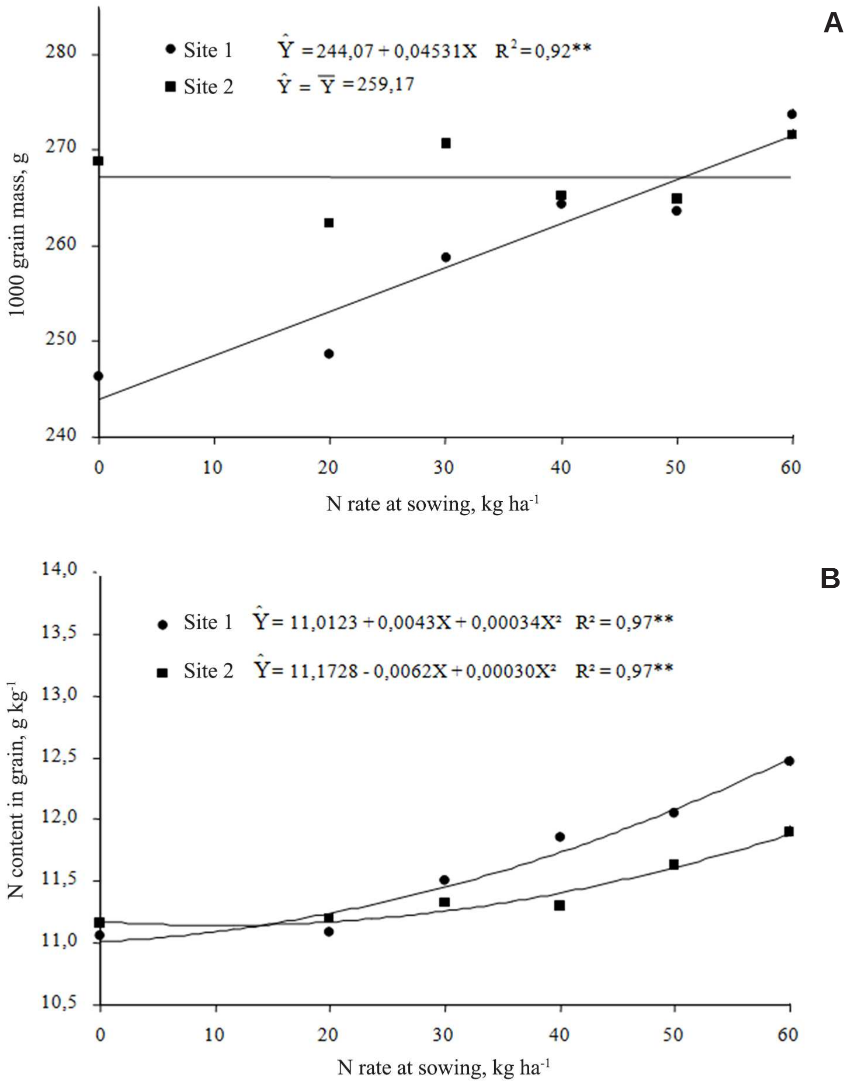

Figure 2. Thousand grain mass (A) and N content in maize grain (B) in response to nitrogen fertilization at sowing for areas without (Site 1) and with crop rotation (Site 2).

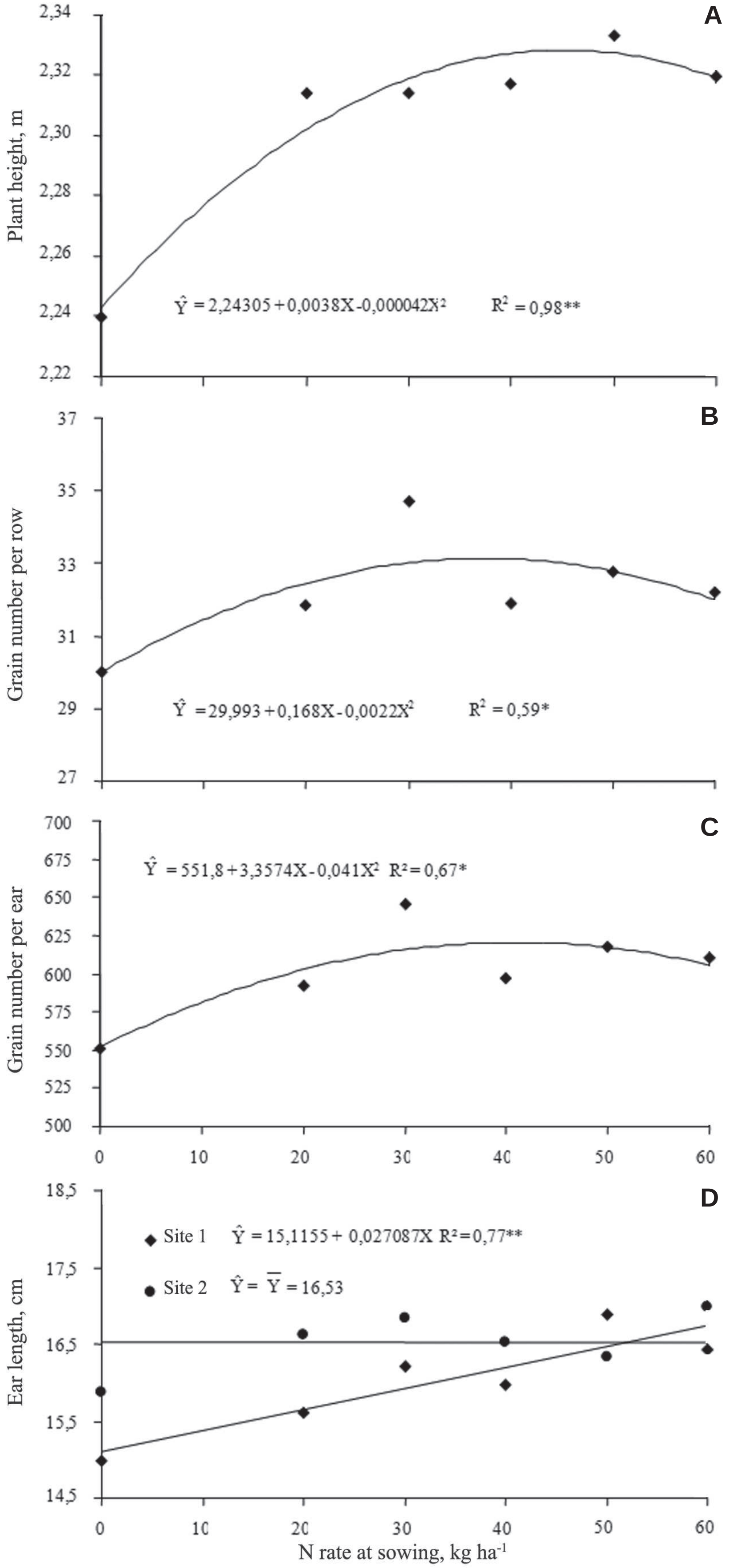

Figure 3. Plant height (A), grain number per row (B), grain number per ear (C) and ear length for areas without (Site 1) and with crop rotation (Site 2) (d) in response to nitrogen fertilization at sowing.

(Figure 2b), a trend also observed by Fornasieri Filho (2007). This increase may be related to the higher content of P in the soil of this site and the nutritional balance of the plants, which emphasizes the importance of good management of soil fertility for maize cultivation. The presence of adequate levels of P stimulates N uptake, in the same way that N has a positive effect on the absorption of P by stimulating root growth at the site where N is in the highest concentration (Novais *et al.*, 2007).

The agronomic traits such as plant height, ear length, grain number per row and grain number per ear tended to increase as a function of nitrogen fertilization at sowing (Figure 3), which was also reported by Fancelli & Dourado Neto (2002). Difference for plant height occurred only as a function of N rates at sowing (Table 1), with increase in height up to the rate 45.2 kg N ha^{-1} (Figure 3a). Increase in plant height was also observed by Lana *et al*. (2009), with increasing applications of N. The largest grain number

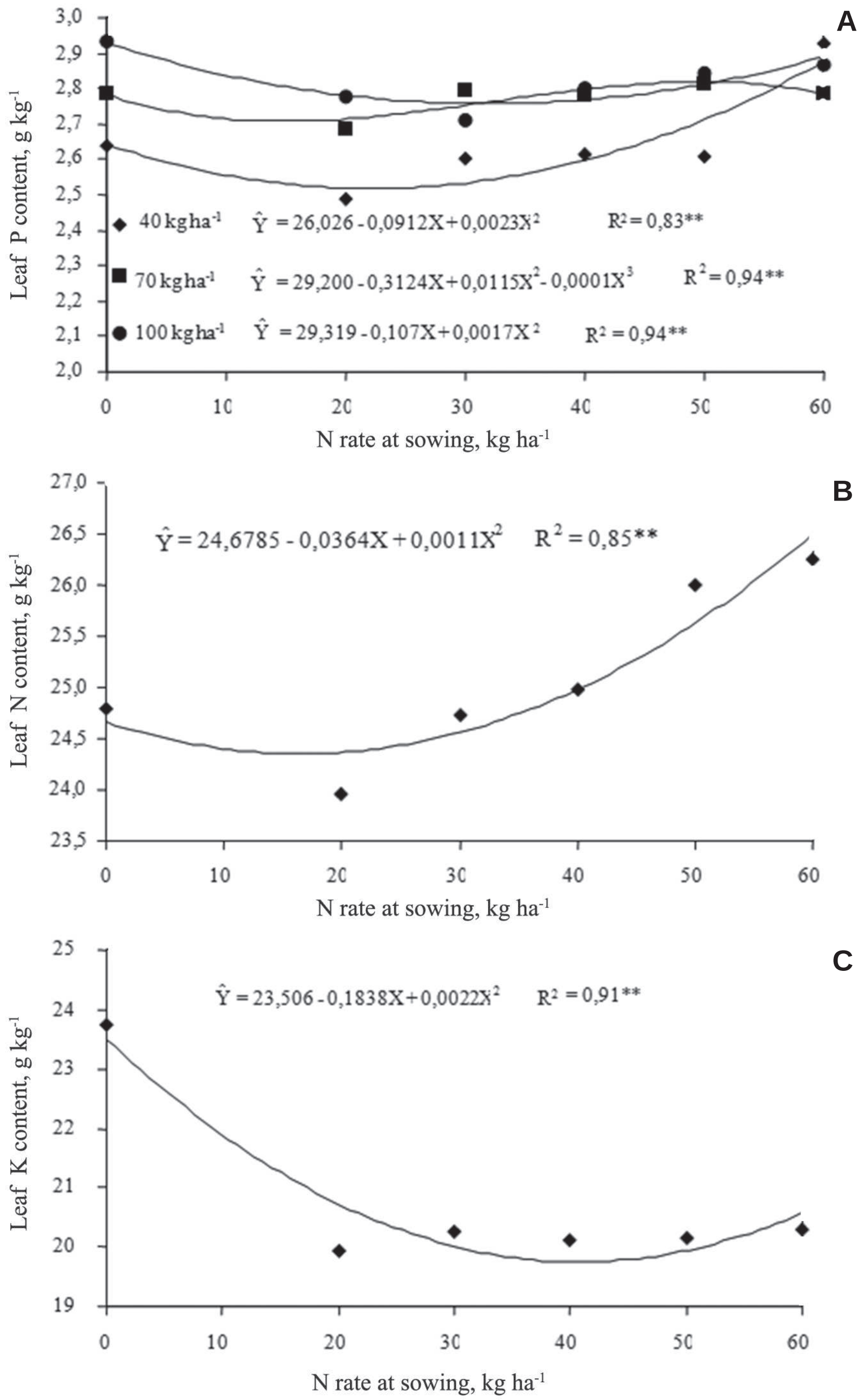

Figure 4. Leaf phosphorus content as a function of N applications at sowing and topdressing (A), leaf nitrogen content (B) and leaf potassium content (C) in response to nitrogen at sowing.

per row as a function of N rates at sowing was obtained with the rate 38 kg ha^{-1} N.

There was difference for the row number per ear between the sites, with Site 1 having a higher mean (Table 1). This fact can be explained by the higher contents of P and K in the soil of Site 1. There was no effect of N at sowing for this variable. However, even with the Site 1 having larger row number per ear, there was no difference in the grain number per ear between the sites (Figure 3c) and this is probably due to the smaller ear length of Site 1 (Figure 3d).

Costa *et al*. (2012) found that in the intercropping (maize + *brachiaria*), the row number, grain number per row and grain number per ear were directly associated and had linear increase with topdress N rates, showing the key role of this nutrient for the maize grain formation. The same fact was reported by Lana *et al*. (2009), emphasizing the important role of N for the agronomic performance of crops and production components.

There was a significant interaction between N rates at sowing and sites for ear length (Table 2). At Site 1, a linear increase of 0.027 cm was recorded for each kg ha^{-1} of N applied at sowing (Figure 3d). However, no difference was found for Site 2 as a function of N rates at sowing, with a mean of 16.53 cm for ear length.

The leaf N content increased from the N rate 16.5 kg ha^{-1} at sowing (Figure 4b). However, even with the highest rate of N at sowing (60 kg ha^{-1} N) the leaf N content was below the adequate levels recommended by Oliveira (2004). This low leaf N may be due to the dilution effect in the plant, since there was increase in plant height with rates up to 45.2 kg ha^{-1} N at sowing (Figure 3a). This result differs from that obtained by Costa *et al.* (2012), who found that the leaf N content increased linearly with increasing levels of N.

The leaf K^+ content decreased with N rates at sowing up to 41.8 kg ha^{-1} N, but increased from that rate (Figure 4c), i.e., without N fertilization at sowing, K^+ concentration was higher than that found with increasing N rates at sowing, probably because of the lower plant growth, which resulted in higher K^+ concentrations.

For leaf P content, there was difference between the sites and significant interaction between N rates at sowing and topdressing (Table 1). Site 1 had mean P content greater than Site 2, possibly due to the higher initial concentration of P in the soil. However, the contents were within the range considered adequate for the crop (Oliveira 2004).

In the interaction of leaf P content with the N rates, at sowing and in topdressing, there was a tendency to equate the P contents at the highest N rate at sowing (60 kg ha^{-1}). These results show a positive interaction between N and P, that is, increased N at sowing resulted in increased P absorption, especially at the rate 40 kg ha^{-1} N in topdressing, even for soils with high P available, in which there is usually little response to fertilization (Figure 4a).

CONCLUSIONS

Split nitrogen applications, with the highest rate applied at sowing, for the same final amount of fertilizer, resulted in higher grain yield.

The rate 70 kg ha^{-1} nitrogen in topdressing provided the highest yield the lowest cost, compared with the yield obtained with the rates 40 and 100 kg ha^{-1}.

The crop rotation (maize + soybean + oat + soybean + maize) provided significant increase (7%) in maize yield compared with the sequential maize cultivation.

Increased nitrogen at sowing increased the 1000 grain mass, plant height, ear length, grain number per row and grain number per ear.

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