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ORIGINAL ARTICLE

Management and cost of urea application in maize grown in northern Paraná state, Brazil

Manejo e custo da aplicação de uréia no milho cultivado na região Norte do Paraná

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ABSTRACT: Urea is the most widely used nitrogen fertilizer in maize. In this study, we aimed to evaluate the agronomic performance of maize under different rates and forms of N application and to identify the economic efficiency provided by this crop in relation to this type of fertilizer. To this end, we conducted a field experiment in a Eutroferric Dark Red Latosol (Oxisol) using the maize cultivar AG 8021. Nine treatments were tested comprising the application of 40, 80, 120, 160, 200, and 240 kg ha^{-1} of N (urea) as topdressing; 80 and 120 kg ha^{-1} of N as topdressing and incorporated into the soil; and a control treatment containing only the N from the compound at sowing. We assessed the components of production, yield, and economic analysis of urea maximum efficiency with respect to crop yield. The different rates of N used – both as topdressing and incorporated – improved the production and yield components of maize. Nitrogen application rates of 120 kg ha^{-1} as topdressing and of 80 kg ha^{-1} incorporated into the soil presented greater economic efficiency.

KEYWORDS
Nitrogen fertilizer
Production cost
Profit margin
Zea mays L.

RESUMO: *A uréia é o adubo nitrogenado mais utilizado na cultura do milho. Com os objetivos de avaliar o desempenho agronômico de milho, cultivado sob diferentes doses e formas de aplicação de adubação nitrogenada, e de identificar a eficiência econômica proporcionada pela cultura em relação ao fertilizante, foi realizado o experimento em Latossolo Vermelho Escuro Eutroférrico, utilizando-se a cultivar AG 8021. Foram testados nove tratamentos, que consistiram na aplicação de 40, 80, 120, 160, 200 e 240 kg ha^{-1} de N (uréia), em cobertura; 80 e 120 kg ha^{-1} de N em cobertura e incorporado ao solo, e um controle, contendo apenas o N proveniente do formulado na semeadura. Foram avaliados os componentes de produção, produtividade e análise econômica da eficiência máxima da uréia com relação à produtividade. As doses de N, tanto em cobertura quanto incorporadas, possibilitaram melhorias nos componentes de produção e produtividade do milho, sendo que as doses de 120 kg ha^{-1} de N em cobertura e de 80 kg ha^{-1} de N incorporado demonstraram maior eficiência econômica.*

PALAVRAS-CHAVE
Adubo nitrogenado
Custo de produção
Margem de ganho
Zea mays L.

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1 Introduction

Maize (*Zea mays* L.) is one of the most important products for human and animal consumption (SILVA, D. R. G. et al., 2011). The northern region of Paraná accounts for approximately 30% of the production of this state (PARANÁ, 2012). Among the key factors that contribute to the yield gains verified in this culture are the significant increase in the use of nitrogen fertilizers and changes in plant population per area, and the use of technologies for genetic improvement (SANGOI et al., 2001).

In order to show all its production potential, maize requires that its nutritional requirements be fully met and therefore plants draw large amounts of nutrients from the soil (AMARAL FILHO et al., 2005). Accordingly, this culture requires greater amounts of nitrogen (N) because of its use in topdressing to supplement the amount supplied by the soil (ARATANI; FERNANDES; MELLO, 2006; DEPARIS; LANA; FRANDOLOSO, 2007). In the management system currently adopted part of the N is applied at sowing and the rest when plants present four to eight unfolded leaves (RAIJ et al., 1996).

Currently, urea is the most widely used nitrogen fertilizer because it can be easily found in the market and it presents high N concentration (45%) and low cost per unit. However, it should be handled carefully because of its high hygroscopicity and greater susceptibility to loss by evaporation, especially when surface applied on soils with low moisture content or on straw from crops grown in succession system (SILVA, A. A. et al., 2012).

Incorporation to the soil is a technique that minimizes urea loss by volatilization of ammonia (N-NH_3^+). In this process, N-NH_3^+ finds soil sites with pH values lower than that found around the granules of fertilizer and it is transformed into ammonium (N-NH_4^+), which is not volatile and is adsorbed into the negative charges of the soil (LARA CABEZAS et al., 2000).

The use of a particular technology influences directly in production costs and also determines crop yield (KANEKO et al., 2010). Even with proper management adopted with the fertilizer, the use of estimates of production costs is of great significance in the efficiency analysis of a given economic activity and its specific processes, which indicate the success of a particular rural enterprise in its production efforts. At the same time, as agriculture becomes more competitive, production costs constitute important information in decision making (MARTIN et al., 1998). Because it is the factor that burdens crop costs the most (SILVA, E. C. et al., 2005), determining the economic N rates is of major importance for the rationalization of production costs and higher profits (BASTOS et al., 2008).

In this study, we aimed to assess the agronomic performance of maize grown under different rates and forms of nitrogen fertilizer application (Urea - 45% N) identifying the gross profit margin provided by crop yield in relation to this fertilizer.

2 Materials and Methods

This experiment was conducted under field conditions in a soil classified as Eutroferric Dark Red Latosol (Oxisol), located in the municipality of Sertanópolis, Paraná state (latitude 22° 58' S and longitude 51° 01' W); Cfa humid subtropical climate with hot summers (KÖPPEN, 1948). Daily data of air temperature, rainfall, and insolation collected at the Meteorological Station of the Agronomic Institute of Paraná - IAPAR during the development of the crop studied in the field are presented in Figure 1.

Prior to experiment installation, soil sampling was performed at 0-20 cm depth for determination of soil chemical attributes with the following results: pH in $CaCl_2$ = 5.2, organic matter (OM) = 10.7 g kg^{-1}, available phosphorus (P) (Mehlich 1) = 14 mg dm^{-3}, potential acidity (H+Al) = 4.6 $cmol_c$ dm^{-3}, calcium (Ca) = 5.4 $cmol_c$ dm^{-3}, magnesium (Mg) = 3.1 $cmol_c$ dm^{-3}, potassium (K) = 0.3 $cmol_c$ dm^{-3}, cation exchange capacity (CEC) = 13.4 $cmol_c$ dm^{-3}, and base saturation (V) = 66%] obtained according to the methodologies described by Embrapa (1997).

We used the maize cultivar AG 8021®, early maturity, medium-sized plant, spaced at 0.90 m between rows, eight seeds per linear meter. Seeds were treated with insecticides thiamethoxam, 175 g of a.i. (active ingredient) per 100 kg of seed and thiodicarb 105 g of a.i. per 100 kg of seed just before

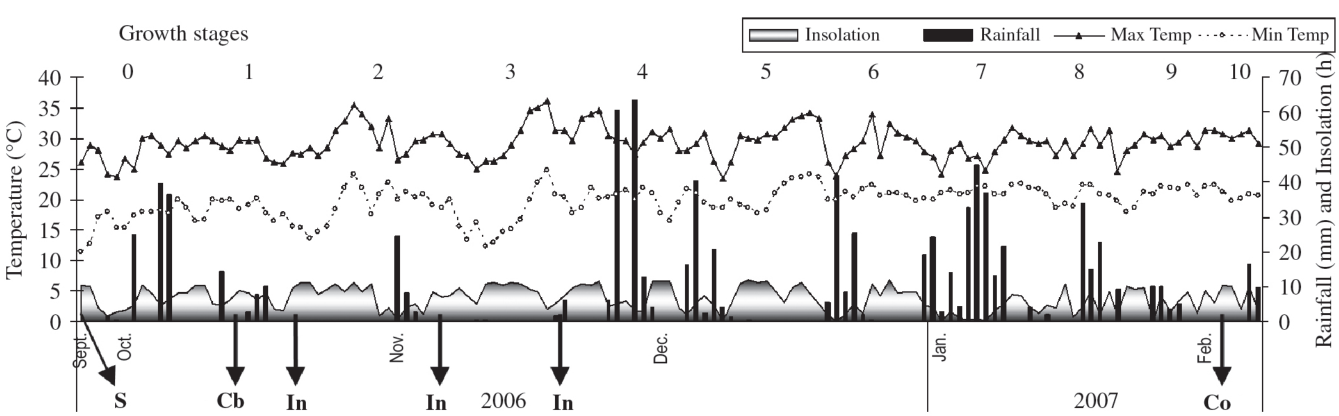

Figure 1. Growth stages of maize plants (FANCELLI, 1986); daily data of maximum and minimum air temperature (lines), rainfall (bars), and insolation (area) between September 2006 and February 2007. S: Sowing; Td: Topdressing (17 days); In: Insecticide (25, 40 and 55 DAS); and H: Harvest (130 DAS).

sowing. Sowing fertilization consisted of 227.3 kg ha^{-1} of the compound 8-20-20 (N-P2O5-K2O).

Nine treatments were tested using a randomized block design. The treatments comprised the application of 40, 80, 120, 160, 200, and 240 kg ha^{-1} of N (urea) as topdressing; 80 and 120 kg ha^{-1} of N as topdressing and incorporated into the soil; and a control treatment containing only the N from the compound at sowing, with five replications each. Each experimental unit consisted of eight 6 m long rows. Three rows from the plot center, disregarding 2 m at the ends of each row, were considered for assessment of phytotechnical factors. Nitrogen topdressing was performed 17 days after sowing (DAS) distributed in the interrow, and the other treatments received N fertilization incorporated into the soil, in the interrow center, approximately 5 cm deep. During crop development the experimental area was monitored for pests, diseases and weeds. There was the need to control the fall armyworm (*Spodoptera frugiperda*) at 25 DAS using methyl parathion, 324 g ha^{-1} of a.i. and lufenuron, 6 g ha^{-1} of a.i.; while at 40 DAS lufenuron, 15 g ha^{-1} of a.i. was applied, and at 55 DAS, spinosad, 34 g ha^{-1} of a.i. was applied.

The crop was harvested manually 130 DAS, when the grains presented 20% humidity. The production and yield components were then assessed. In order to determine these components 15 ears were collected from the central row of parcels aiming at the following assessments: ear length (with ears already detrashed, the distance between first and last grains of the longest line was measured, thereby obtaining the mean length value of ears in centimeters); ear diameter (obtained in the middle region of the ear with the aid of a manual caliper, results expressed in cm); grain mass [obtained by weighing the grains harvested from the useful area of the plot, with humidity corrected to 13% (moisture storage for maize grains), and grain yield adjusted to kg ha^{-1}]. Data were subjected to analysis of variance (ANOVA), the F test and means compared by the Tukey test ($p \leq 0.01$) and regression study for the effect of N rates on yield, adopting the magnitude of the regression coefficients ($p \leq 0.05$) as a criterion for choosing the model. The different managements of nitrogen (rate and application) of each treatment were considered in the economic analysis. The values used for the calculations were in dollars because the product to be marketed is a commodity, and the amount paid for the input was US$ 213.7 t^{-1} of urea (INDEXMUNDI, 2012). For the maize we used the average price received by producers at harvest time, equivalent to US$ 9.4 per 60 kg sack. Based on the mean grain yield of each treatment, we calculated the Increase in Maize Yield (IMY) in proportion to the control treatment, the Production Value (PV) corresponding to this increase in yield (gross), and the respective Gross Profit Margin (GPM). These variables were also calculated using the data of each treatment compared with the immediate lower rate.

3 Results and Discussion

The climatic conditions that occurred during the crop cycle were considered sufficient for the proper development of maize. We observed that, at the time of flowering – growth stage V_6 (MAGALHÃES; DURÃES, 2006), a phase which determines the amount of egg cells to be fertilized and consequently the grain production (PENARIOL et al., 2003), rainfall occurred before and after this stage allowing plants to express their production potential (Figure 1).

Length and diameter of ears and grain mass showed no significant differences between N rates applied as topdressing and incorporated into the soil, differing only in relation to the control (Table 1). According to Pereira Filho and Cruz (2002), there is a direct relation between growth characteristics and yield. Similar results were obtained by Lourente et al. (2007), who observed significant effect of topdressed N rates of 50, 100 and 200 kg ha^{-1} on length and diameter of ears. In the same experiment, they also found ears presenting maximum diameter of 46.54 mm and length of 18.12 cm with N rate of 200 kg ha^{-1}. Kappes et al. (2009) verified greater diameter of ears when N was applied to plants presenting 10 fully unfolded leaves. Factors such as the different climatic conditions of the two experiments, cultivars, soil type and yield can influence these results.

With respect to grain mass, Casagrande and Fornasieri Filho (2002) when studying the influence of rates and time of N application at sowing and at five-to-six-leaf stage in off-season maize, reported no effect of time of application and rates of N in yield characteristics such as thousand-grain

Table 1. Mean values for length (EL) and diameter (ED) of ears and grain mass (GM) in maize cultivated under different rates of N topdressing application.

N rates	Form of application	EL	ED	GM
kg ha^{-1}		cm		g ear^{-1} -
40	Topdressing	13.59 a	4.53 a	125.87 a
80		14.30 a	4.54 a	133.07 a
120		14.80 a	4.58 a	143.47 a
160		14.62 a	4.60 a	141.50 a
200		14.52 a	4.57 a	143.60 a
240		14.63 a	4.61 a	146.40 a
80	Topdressing and Incorporated	14.48 a	4.58 a	142.00 a
120		14.49 a	4.56 a	142.00 a
Control		11.20 b	4.21 b	85.73 b

[1]Means followed by the same letter in the column do not differ by the Tukey test at 1% probability level.

mass; the same was observed in the present study. On the other hand, Amaral Filho et al. (2005) and Edson Cabral da Silva et al. (2005), in different soil and climatic conditions from the present study, obtained an increase in grain yield with N topdressing in maize, diverging from the results herein presented.

The method of fertilizer application did not affect the production of grain mass (Table 2). Such result can be explained by Oliveira and Caires (2003), who reported that urea applied as topdressing or incorporated into the soil presents behavior similar to sprayed ammonium sulfate on maize nutrition and production when there is rainfall between the second and fourth days following application, which causes the fertilizer to be incorporated into the soil and prevents N-NH_3 loss by evaporation.

Maize yield showed quadratic fit as a function of N topdressing rates (Figure 2), reaching maximum estimated yield at the application rate of 176.8 kg N ha^{-1}, with estimated production of 10914.8 kg ha^{-1}. Aratani, Fernandes and Mello (2006) found linear response for grain yield when assessing N topdressing rates at growth stage V_5 (MAGALHÃES; DURÃES, 2006). For Deparis, Lana and Frandoloso (2007), under the soil and climate conditions of Cascavel (PR), and for Biscaro et al. (2011), under the environmental conditions of Dourados (MS), the effects of N topdressing fertilization in growth stages V_6 and V_8, and V_4 and V_7, respectively, achieved a linear increase in yield up to the rates of 152 and 261 kg ha^{-1} of N, respectively.

When N was applied incorporated into the soil, both rates (80 and 120 kg ha^{-1}) promoted yield greater than that of the control treatment, but with no difference between the rates (Figure 3). Urea presents high efficiency when incorporated into the soil because the entire process of volatilization is minimized. Losses of ammonia (NH3-N) by evaporation are potentially higher when ammonium and/or amide fertilizers are topdressed on dry soils (BOUWEESTER; VLEK; STUMPE, 1985; LARA CABEZAS et al., 2000; OLIVEIRA; CAIRES, 2003). In addition, volatilization may be intensified if large amounts of straw from the previous crop remain on soil surface.

The average maize yield in the state of Paraná in 2007 was 5213 kg ha^{-1} (PARANÁ, 2012), this value is 17.4% lower than that observed in the control treatment (with no N topdressing) of the present study (Figures 2 and 3); nevertheless, if the maize yield of northern Paraná state (6670 kg ha^{-1}) is considered, a similar yield is observed. However, in the other treatments (40, 80, 120, 160, 200 and 240 kg ha^{-1} N topdressing and 80 and 120 kg ha^{-1} incorporated into soil between rows) these values were higher than the local average with mean increase of 73% in yield (Figures 2 and 3).

Regarding the cost of fertilizer and gross profit margin of each nitrogen fertilization management used (Table 2), we verified that the highest gross profit margins were obtained with 120 kg ha^{-1} N topdressing and 80 kg ha^{-1} N incorporated in the interrows (Figure 4) because of the high yields obtained with each rate and the cost of fertilizer per treatment.

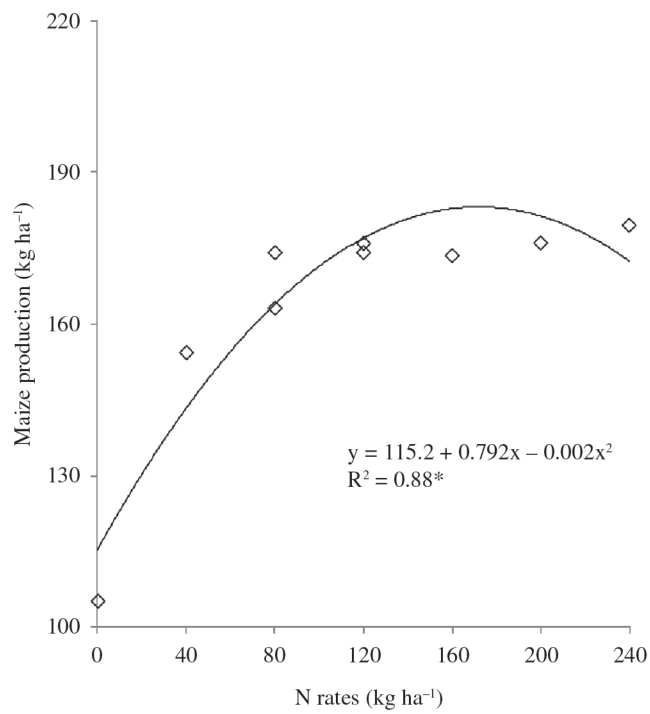

Figure 2. Maize production under different rates of N topdressing (0, 40, 80, 120, 160, 200 and 240 kg ha^{-1}). *Significant at 5% by the F test.

Table 2. Maize grain yield, increase in yield and production value, cost of fertilizer application, and gross profit margin at different rates and forms of urea application.

N rates	Form of application	Grain yield	Increase		Cost of fertilizer	Gross profit margin
			Yield	Production value		
- kg ha^{-1} -		sacks/ha			US$	
40	Topdressing	154.4	49.2	462.1	19.0	443.1
80		163.2	58.1	545.0	38.0	507.0
120		176.0	70.8	664.7	57.0	607.7
160		173.6	68.4	642.1	76.0	566.2
200		176.1	71.0	666.2	95.0	571.3
240		179.6	74.4	698.5	114.0	584.5
80	Topdressing and Incorporated	174.2	69.0	647.8	38.0	609.8
120		174.2	69.0	647.8	57.0	590.8
Control		105.2	-	-	-	-

Under the soil and climate conditions of Selvíria (MS), the application of 60 kg ha^{-1} of N was economically recommended, with higher return rate and profit margin even with the low yield of 5797.3 kg ha^{-1} (ARATANI; FERNANDES; MELLO, 2006). However, Souza et al. (2012) when evaluating the effect of sources, rates and times of N application on production cost and profitability of maize, even with the additional cost of irrigation, observed that the highest gross revenue was achieved with N topdressing rate of 200 kg ha^{-1}, obtaining yields of 12,300 kg ha^{-1} (205 sacks/ha) and 9780 kg ha^{-1} (163 sacks/ha) in the 2007/2008 and 2008/2009 crops, respectively.

Factors such as appropriate soil and nitrogen management in maize crop with different tillage systems and application periods in no-tillage, provides greater gross revenue when N is applied at sowing and at growth stages V_4 and V_8 (KANEKO et al., 2010).

The gross margin achieved at the rate of 160 kg ha^{-1} N in relation to the rate of 120 kg ha^{-1} N topdressing showed negative effects, as well as the rate of 120 kg ha^{-1} N compared with the rate of 80 kg ha^{-1} N incorporated (Table 3). Possibly, this result occurred because the increase in yield was not enough to compensate for the costs of nitrogen fertilization. In the treatments adopted under the soil and climate conditions studied and the cost of fertilizer established, the highest profit margins were obtained with N topdressed and incorporated at 40 and 80 kg ha^{-1} rates, respectively, because they did not present costs with topdressing. These results demonstrate that, form the economic standpoint, the N fertilizer application rate corresponding to the highest grain yield is not the most profitable, and therefore not the most recommended for producers (BARBOSA FILHO; FAGERIA; SILVA, 2005).

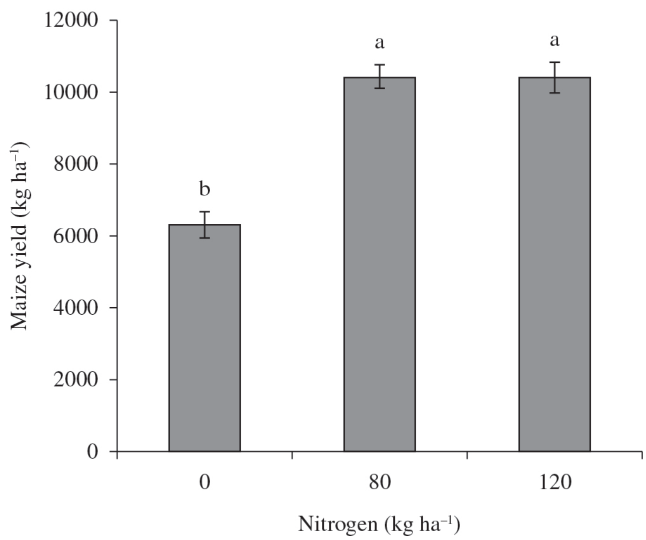

Figure 3. Maize yield as a function of N rates applied as topdressing and incorporated into soil in the interrows. Means followed by different letters differ by the Tukey test at 5% probability level.

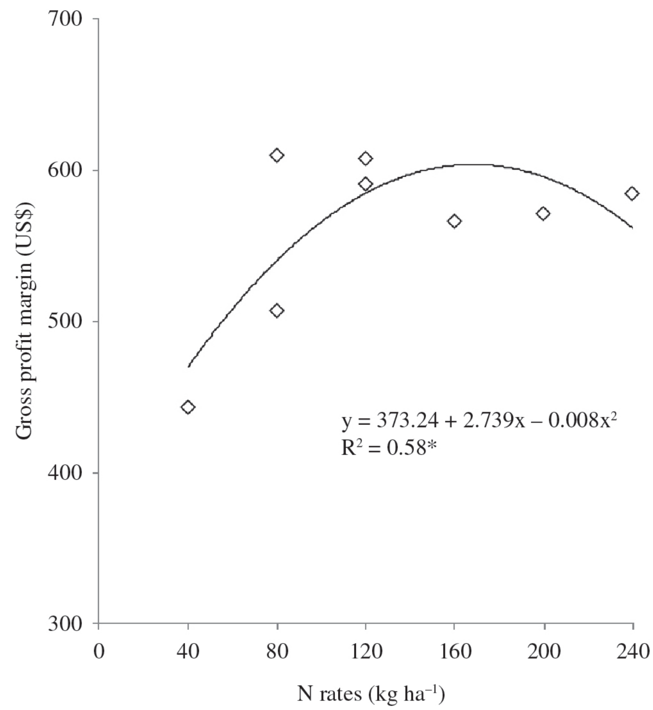

Figure 4. Ratio between the rates of N applied as topdressing or incorporated into soil and the gross profit margin of maize crop. *Significant at 5% by the F test.

Table 3. Rates and forms of urea application, increase in grain yield and production value of maize, and gross profit margin compared with the previous rate of nitrogen fertilization.

N rates	Forms of application	Increase[1]		Gross profit margin[2]
		Yield	Production value	
- kg ha⁻¹ -		sacks/ha	US$	
40	Topdressing	49.23	462.06	443.07
80		8.83	82.89	63.90
120		12.76	119.74	100.74
160		–2.41	–22.64	–41.64
200		3.33	125.88	106.88
240		3.43	32.24	13.24
80	Topdressing and Incorporated	69.02	647.81	609.82
120		0	0	–19.00

[1]Increases obtained compared with the immediate lower rate of N considering control production of 105.16 sacks of 60 kg ha^{-1}. [2]Value obtained by subtracting the difference between the cost of fertilizer for the current rate and the rate previous to the increase from the production value.

4 Conclusions

N fertilization rates applied as topdressing and incorporated into the soil promoted an increase in the components of maize production, and the highest maize crop yield was obtained with the N estimated rate of 177 kg ha^{-1}.

The highest gross profit margin was obtained with urea at the N rates of 120 kg ha^{-1} as topdressing and 80 kg ha^{-1} incorporated into the soil.

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