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Productivity and profitability of maize as affected by nitrogen sources and rates

Produtividade e lucratividade do milho afetadas pela aplicação de fontes e doses de nitrogênio

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Highlights

Stabilized and protected urea applied as sources of N did not increase maize yield.
Lower costs of conventional and NBPT-treated urea resulted in higher profitability.
The maximum economic efficiency of NBPT-treated urea was achieved with a low N rate.

Abstract

The use of nitrogen (N) sources that reduce N losses may be an interesting management strategy to increase the economic and environmental sustainability of maize crops. This study aimed to assess the effects of different N sources and rates on maize grain yield and crop profitability. The experiment was conducted in the field on a Red Nitisol of clay texture during two growing seasons. The experimental design was a randomized block with split plots. Four sources of N were applied to the main plots: conventional urea, protected urea, urea treated with nitrification inhibitor, and urea treated with urease inhibitor. Split plots were treated with four N rates: 0, 140, 280, or 420 kg N ha^{-1}. The four N fertilizer sources produced no differences in grain yield, which ranged from 3.2 to 15.9 Mg ha^{-1}. This parameter showed a quadratic response to increasing N rates, regardless of N source. Theoretical N rates for optimal grain yield were estimated at 407 and 411 kg N ha^{-1} in 2016/2017 and 2017/2018, respectively. The highest profitability indices were obtained by applying 378 kg N ha^{-1} from conventional urea in 2016/2017 and 278 kg N ha^{-1} from urea treated with urease inhibitor in 2017/2018.

Key words: *Zea mays.* Economic analysis. Nitrogen fertilizers. Grain yield.

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Resumo

A utilização de fontes nitrogenadas que reduzam perdas de N pode ser uma estratégia de manejo adequada para aumentar a sustentabilidade econômica e ambiental no cultivo do milho. Este trabalho foi conduzido com o objetivo de avaliar os efeitos de fontes e doses de nitrogênio sobre a produtividade de grãos do milho e a lucratividade da lavoura. O experimento foi conduzido a campo, em dois anos agrícolas, num Nitossolo Vermelho de textura argilosa. O delineamento experimental foi de blocos ao acaso, dispostos em parcelas subdivididas. Na parcela principal foram testadas quatro fontes de N: ureia convencional, ureia protegida, ureia com inibidor de nitrificação e ureia com inibidor de urease. Nas subparcelas foram testadas quatro doses de nitrogênio: 0, 140, 280 e 420 kg de N ha^{-1}. As quatro fontes de fertilizantes nitrogenados não apresentaram diferenças no rendimento de grãos. A produtividade de grãos variou de 3,2 a 15,9 Mg ha^{-1}. Ela apresentou uma resposta quadrática ao aumento da dose, independentemente da fonte de N. As doses teóricas que otimizaram a produtividade de grãos foram de 407 e 411 kg N ha^{-1} em 2016/2017 e 2017/2018, respectivamente. Os maiores índices de lucratividade foram obtidos pela aplicação das doses de 378 kg de N ha^{-1} com ureia convencional em 2016/2017 e 278 kg de N ha^{-1} de ureia com inibidor de uréase em 2017/2018.

Palavras-chave: Análise econômica. Fertilizantes nitrogenados. Rendimento de grãos. *Zea mays.*

Introduction

Nitrogen (N) fertilization is crucial for maize crops because N is the nutrient with the greatest effect on crop yield (Coelho et al., 2020) and high N rates are needed for obtaining high grain yields (Coelho et al., 2022). Conventional urea is the most common N source used by maize farmers worldwide (Heffer & Prud'homme, 2016). The popularity of conventional urea can be explained by its high N content (44–46%), low cost, and ease of application (Ribeiro et al., 2020). On the other hand, its greatest disadvantage is the high susceptibility to ammonia (NH_3) volatilization. Urea dissolves when hydrated and, upon exposure to the urease enzyme, it turns into ammonium carbonate, increasing the pH around fertilizer granules and favoring NH_3 emission. NH_3 volatilization reduces the response of productivity to N fertilization (Frazão et al., 2014), generates negative environmental impacts (Keeler et al., 2016; Gourevitch et al., 2018), and decreases the profitability of maize crops.

Important innovations have emerged on the N fertilizer market in recent years, with new technologies aimed at reducing N loss, increasing N use efficiency, and providing economic and environmental advantages to maize crops. Among the innovations is stabilized urea. Stabilized N sources contain urease or ammonia monooxygenase inhibitors together with urea in the granule structure. The main urease inhibitor used by farmers is N-(n-butyl)thiophosphoric triamide (NBPT). NBPT competes with urea for the active site of urease, inhibiting ammonia losses (Ribeiro et al., 2020). 3,4-Dimethylpyrazole phosphate (DMPP) prevents the conversion of ammonium to nitrate, reducing N losses by nitrate leaching into the soil. In addition to that, stabilized N sources also mitigate nitrous oxide emissions (McCarty, 1999; Cantarella et al., 2018).

Another strategy for reducing N losses is the use of controlled-release fertilizers, such as slow-release urea (Zhang et al., 2019). Slow-release formulations typically consist of urea granules coated with sulfur resins or water-permeable polymers that gradually release nutrients through osmosis (Trenkel, 2010). Slow-release N sources reduce losses associated with ammonia volatilization and nitrate leaching. Thus, these fertilizers can enhance maize yield and the economic efficiency of N use.

Studies investigating fertilizer sources that minimize N losses have focused on sandy soils, given that clay soils are less susceptible to N losses by ammonia volatilization or nitrate leaching (Cameron et al., 2013, Pelster et al., 2019), even though they have higher emission rates of nitrous oxide (Jamali et al., 2016). The higher the N rate applied, the greater the potential for N loss (Cantarella et al., 2018). This argument has been used to explain the intense commercial growth of alternative N sources for clay soils in southern Brazil. Such fertilizers have been used to provide high N rates to high-tech crops. However, it is unclear whether the application of high N rates from stabilized or controlled-release sources to clay soils is an effective strategy for increasing productivity and minimizing economic losses. This study aimed to investigate the effect of different N sources and rates applied by topdressing on maize productivity and profitability in a soil with high clay contend.

Material and Methods

The experiment was set in Campos Novos, Santa Catarina State, Brazil, during the growing seasons of 2016/2017 and 2017/2018. The experimental site is located at 27°24'0"S 51°13'30"W and 934 m above sea level. The climate is classified as temperate Cfb according to the Köppen classification system. The soil is a dystrophic Red Nitisol. The experimental site has a flat topography and was managed under a no-till system. In October 2016, soil chemical and physical properties in the 0–20 cm layer were as follows: 60% clay, pH (H_2O) 5.6, 3.8% organic matter, SMP index of 5.6, 16.3 mg dm^{-3} P, 91 mg dm^{-3} K, 9.9 cmol$_c$ dm^{-3} Ca^{2+}, 4.3 cmol$_c$ dm^{-3} Mg^{2+}, 0 cmol$_c$ dm^{-3} Al^{3+}, and 21.3 cmol$_c$ dm^{-3} cation-exchange capacity. Meteorological data (temperature and rainfall) for the two growing seasons are presented in Figure 1.

The experimental design was a randomized block with split plots and four replications. Twelve treatments were used in the 2016/2017 season. Main plots consisted of three nitrogen sources: conventional urea, DMPP-treated urea, and sulfur-protected urea. Four N top-dress rates were tested in the split plots: 0, 140, 280, and 420 kg N ha^{-1}, equivalent to 0, 0.5, 1.0, and 1.5 times the N rate recommended for Rio Grande do Sul and Santa Catarina States by the Comissão de Química e Fertilidade do Solo [CQFS RS/SC] (2016) for an estimated grain yield of 18,000 kg ha^{-1}. All treatments received a basal fertilization of 30 kg N ha^{-1} at the sowing day. Sixteen treatments were assessed in the 2017/2018 season. Four N sources were tested in the main plots: conventional urea, sulfur-protected urea, DMPP-treated urea, and NBPT-treated urea. The same N doses used in the 2016/2017 season were evaluated in the split plots.

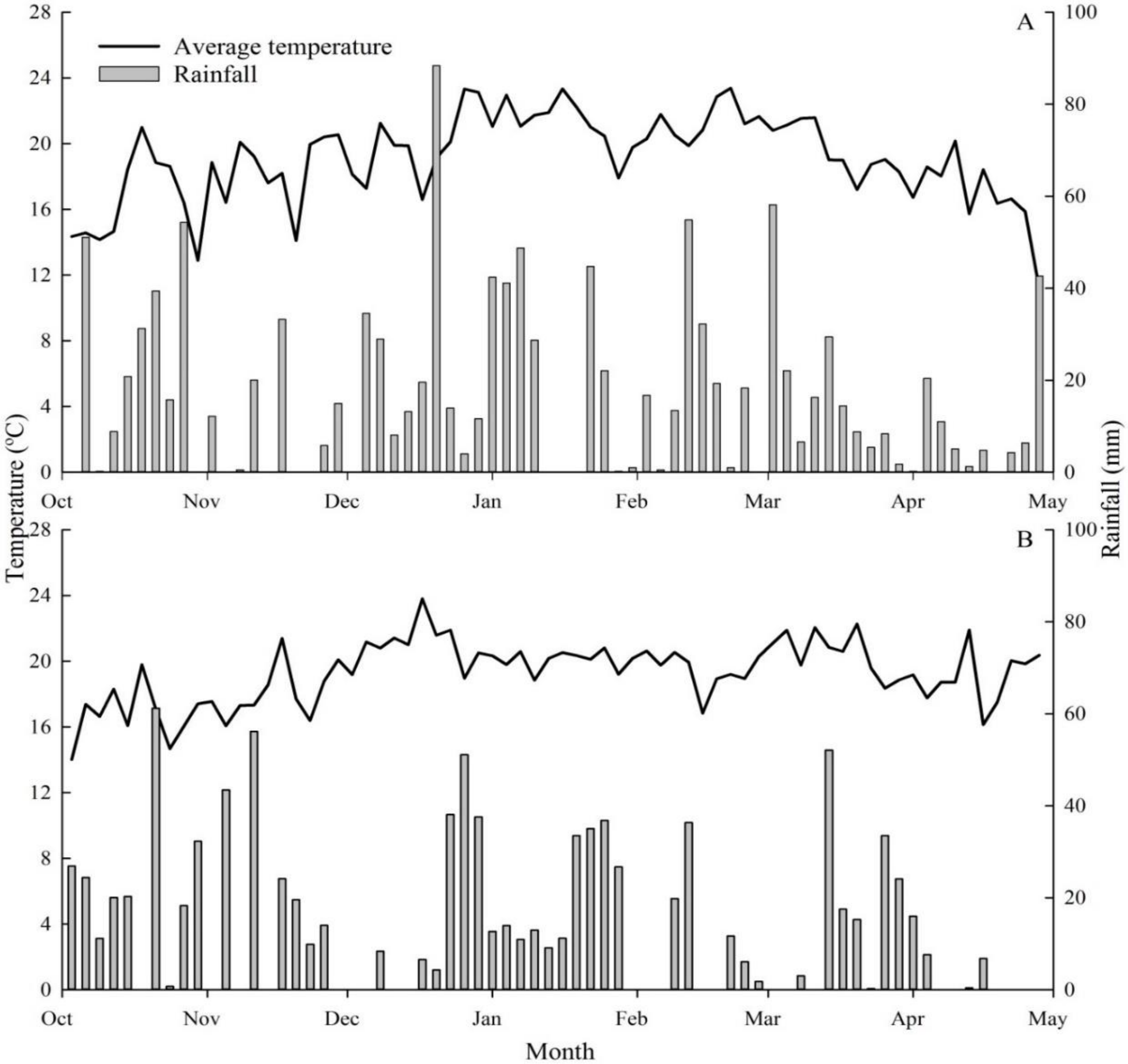


Figure 1. Average temperature and rainfall during the (A) 2016/2017 and (B) 2017/2018 growing seasons of maize crops. Campos Novos, Santa Catarina State, Brazil.

Each split plot consisted of six rows, 6 m in length each, spaced 0.7 m apart. The useful area comprised the four central rows, excluding 0.5 m from the beginning and end of rows. Conventional urea was applied at the V6 stage. DMPP- and NBPT-treated urea were applied when plants were at the V2 stage (Ritchie et al., 1993). Sulfur-protected urea was applied the day after sowing. N fertilizers were applied according to the manufacturer's recommendations with regard to time and method of application. Fertilizers were broadcast manually between rows.

The maize hybrid P30F53VYH was used at a density of 70,000 plants ha^{-1}. Phosphate and potassium fertilizers were applied on the day of sowing at a rate of 512 kg ha^{-1} triple superphosphate and 233 kg ha^{-1} potassium chloride, corresponding to rates of 209 kg ha^{-1} P_2O_5 and 153 kg ha^{-1} K_2O, respectively. Black oat (*Avena strigosa*) was sown at 80 kg seeds ha^{-1} in May of both years. The winter crop was desiccated in mid-August by using a glyphosate-based herbicide (1.4 kg ai ha^{-1}) and 2,4-D (670 g ai ha^{-1}). Maize sowing was carried out on October 13, 2016, and October 23, 2017, using manual seeders. Three seeds were sown per hill to prevent stand failures. At the V2 stage of the scale of Ritchie et al. (1993), plants were manually thinned to the desired population density. Following maize emergence, at the V3 stage, weeding was performed using atrazine (2.25 L ai ha^{-1}). The insecticide beta-cyfluthrin (5 g ai ha^{-1}) was applied at V3 and lambda-cyhalothrin (7.5 g ai ha^{-1}) + chlorantraniliprole (15 g ai ha^{-1}) at V6 for the control of fall armyworm (*Spodoptera frugiperda*).

The following agronomic parameters were evaluated: number of rows of grains per ear, number of grains per row, number of ears per plant, number of grains per square meter, number of grains per ear, thousand grain weight, and grain yield (kg ha^{-1}) at 13% moisture. Number of ears per plot and number of plants per plot were determined at physiological maturity, defined as grain moisture below 23%. Number of ears per plant was determined from the relationship between number of ears and plants in each split plot.

Harvest was carried out manually when grain moisture was between 18 and 23%. Ears in the useful area were harvested and threshed. Kernels were separated, and a sample was used for moisture determination by oven drying at 65 °C to constant weight. Grain yield was determined at 13% moisture. Thousand grain weight at 13% moisture was determined by using a subsample of 400 grains from the useful area of each treatment. Number of grains per ear was estimated indirectly through the relationship between thousand grain weight, total grain weight, and number of ears per split plot. Number of grains per square meter was estimated using grain weight per square meter and thousand grain weight. For determination of number of rows of grains per ear and number of grains per row, 10 ears per split were randomly selected and counted.

Operating costs data on high-tech maize hybrids used in southern Brazil were obtained from the Companhia Nacional de Abastecimento [CONAB] (2020). To determine the profitability of treatments, the method proposed by Martin et al. (1997) was used. Gross revenue was calculated as the product between the number of 60 kg bags produced and the average price of bags (gross revenue = number of bags × price per unit). Operating profit was determined as the difference between gross revenue and total operating cost (operating profit = gross revenue – total operating cost). The profitability index was defined as the proportion of gross revenue made up of available resources after covering total operating costs (profitability index = net revenue/gross revenue × 100).

Agronomic data were subjected to analysis of variance (F-test) at the 5% significance level. When F-values were significant, means of the qualitative factor (N source) were compared by Tukey's test and means of the quantitative factor (N rate) by regression analysis. All comparisons were made at the 5% significance level.

Results and Discussion

The mean grain yields achieved in 2016/2017 and 2017/2018 were 10,510 and 9,110 kg ha^{-1}, respectively (Table 1). Grain yield was 15.4% higher in the first growing season than in the second year, representing a difference of 1,400 kg ha^{-1}. A drought occurred in December of the second year, when plants were between V9 and V12 stages. Furthermore, there was lower water availability during grain filling (Figure 1), resulting in reduced productive potential.

N source did not influence grain yield in both growing seasons (Table 1). There was also no significant interaction between N source and rate (Figure 2A). This finding indicates that the four fertilizers provided a similar N supply in terms of nutrient availability. The lack of effect of N source on grain yield (Table 1) can be explained by the fact that environmental conditions (Figure 1) were unfavorable to N losses by leaching or volatilization (Mota et al., 2015). Furthermore, the study soil is clayey, having low potential for N loss (Cameron et al., 2013; Pelster et al., 2019). The use of high N rates for increased yield might also explain the small differences among treatments.

Thousand grain weight, number of grains per square meter, number of grains per ear, number of rows per ear, number of grains per row, and number of ears per plant did not differ between N sources, following the behavior observed for grain yield (Table 1). The increase in number of rows of grains per ear and number of grains per row with increasing N rate led to an increase in number of grains per ear (Table 1). Likewise, the increase in number of ears per plant and grains per ear with the use of high N rates afforded an increase in number of grains per square meter.

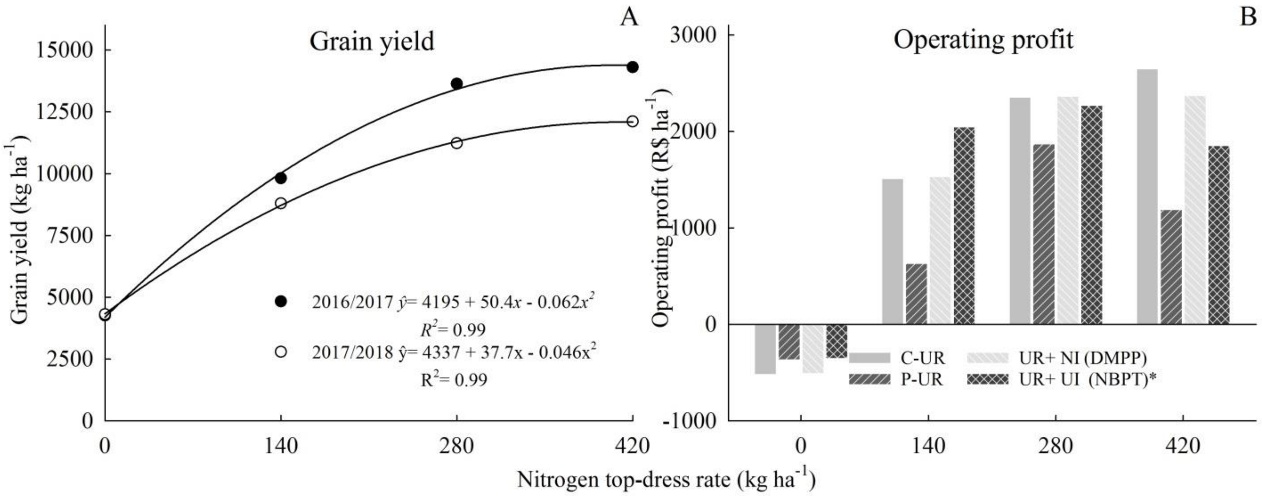
N rate influenced grain yield regardless of the source. There was a quadratic relationship between yield and N rate in both years (Figure 2a). According to the first derivative of the quadratic equations, N rates of 407 and 411 kg ha^{-1} were estimated to provide maximum theoretical yields of 14,380 and 12,089 kg ha^{-1} in 2016/2017 and 2017/2018, respectively. Such an increase in grain yield as a function of N rate is a result of the increase in number of grains per square meter (r = 0.89) and thousand grain weight (r = 0.73). Number of grains per unit area is the yield component most strongly associated with maize yield (Coelho et al., 2022; Sangoi et al., 2019).

Table 1

Grain yield and yield components of maize crops as a function of nitrogen (N) rates and sources applied in the 2016/2017 and 2017/2018 growing seasons. Campos Novos, Santa Catarina State, Brazil

N source or rate	Grain yield (kg ha^{-1})	Thousand grain weight (g)	Grains m^{-2}	Grains ear^{-1}	Rows ear^{-1}	Grains row^{-1}	Ears $plant^{-1}$
			2016/2017				
C-UR	10712^{ns}	362^{ns}	2053^{ns}	438^{ns}	14.9^{ns}	30^{ns}	0.92^{ns}
P-UR	10383^{ns}	367^{ns}	2189^{ns}	447^{ns}	14.6^{ns}	28^{ns}	0.96^{ns}
UR-NI	10437^{ns}	359^{ns}	2082^{ns}	439^{ns}	14.5^{ns}	28^{ns}	0.93^{ns}
CV (%)	6.22	4.23	12.26	9.42	8.04	15.86	5.30
0	4267	300	588	147	13.5	20	0.79
140	9813	338	1982	416	14.6	30	0.97
280	13630	400	2847	584	15.2	32	0.99
420	14333	414	3015	619	15.3	33	0.99
$\hat{Y}$*	$4197 + 50.4x - 0.06x^2$	$302.4 + 0.29x$	$580 + 12.4x - 0.02x^2$	$146 + 2.4x - 0.003x^2$	$13.5 + 0.01x - 0.00001x^2$	$20.4 + 0.08x - 0.0001x^2$	$0.8 + 0.001x - 0.000002x^2$
R^2	0.99	0.95	0.99	0.99	0.99	0.99	0.97
CV (%)	9.03	6.21	14.89	13.64	7.97	14.25	5.71
			2017/2018				
C-UR	8360^{ns}	285^{ns}	1785^{ns}	380^{ns}	14.13^{ns}	31^{ns}	0.96^{ns}
P-UR	8867^{ns}	293^{ns}	1712^{ns}	354^{ns}	15.14^{ns}	32^{ns}	0.99^{ns}
UR-NI	9878^{ns}	295^{ns}	1971^{ns}	394^{ns}	15.08^{ns}	33^{ns}	1.03^{ns}
UR-UI	9336^{ns}	299^{ns}	2016^{ns}	426^{ns}	14.78^{ns}	34^{ns}	0.98^{ns}
CV (%)	15.89	4.38	25.62	25.98	7.61	7.55	12.85
0	4312	270	1194	259	14.53	27	0.96
140	8794	283	1817	380	14.53	33	0.99
280	11226	306	2165	451	14.94	35	0.99
420	12110	312	2310	464	15.13	35	1.01
$\hat{Y}$*	$4337 + 37.7x - 0.046x^2$	$270.9 + 0.1x$	$1197 + 5.2x - 0.006x^2$	$259 + 1.1x - 0.001x^2$	$14.45 + 0.002x$	$27.5 + 0.05x - 0.00007x^2$	$0.96 + 0.00013x$
R^2	0.99	0.96	0.99	0.99	0.89	0.99	0.93
CV (%)	10.74	5.12	24.29	23.73	4.76	11.22	8.29

^{ns} Non-significant differences at $p < 0.05$. C-UR, conventional urea; P-UR, protected urea; UR-NI, urea treated with nitrification inhibitor (DMPP); UR-UI, urea treated with urease inhibitor (NBPT); CV, coefficient of variation; R^2, coefficient of determination. * Mean values for the four N rates tested.



(A) Grain yield of maize crops as a function of nitrogen rates and growing seasons (mean of four nitrogen sources) and (B) operating profit as a function of nitrogen rates and sources (mean of two growing seasons). Models describing operating profit data as a function of nitrogen rates and sources (mean of two crop seasons): conventional urea (C-UR), $\hat{y} = -487.02 + 16.69x - 0.022x^2$, with $R^2 = 0.99$; protected urea (P-UR), $\hat{y} = -473.66 + 13.2x - 0.021x^2$, with $R^2 = 0.91$; urea treated with the nitrification inhibitor DMPP (UR-NI), $\hat{y} = -488{,}78 + 17.64x - 0.026x^2$, with $R^2 = 0.99$; urea treated with the urease inhibitor NBPT (UR-UI), $\hat{y} = -274.83 + 19.96x - 0.036x2$, with $R^2 = 0.97$. *Data from a single season were normalized to the market value of the two seasons under study.

For each unit increase in N rate (kg ha^{-1}), there was a linear increase of 0.3 g and 0.1 g in thousand grain weight in 2016/17 and 2017/18, respectively. Supplementation of plants with high N rates prolongs the physiological activity of leaves (Coelho et al., 2020). This effect may extend the grain filling period, consequently promoting the production of heavier kernels (Coelho et al., 2020). The quadratic response of number of grains to N rate (Table 1) is due to the positive effect of N on photosynthetic rate, which enhances the amount of carbohydrates produced by sources, allowing sinks, such as growing ears, to receive more photosynthates, resulting in a greater number of spikelets and grains per ear (Mota et al., 2015).

The profitability index, which indicates the profit after subtracting all operating costs, varied according to N source and rate, corroborating the findings of Souza et al. (2012). The use of conventional urea applied by topdressing provided positive net profits, regardless of the N rate. In 2016/2017, conventional urea at 420 kg N ha^{-1} afforded a grain yield of 14,457 kg ha^{-1}, generating a profitability index of 35.28% (Table 2). Similar findings were reported by Teixeira et al. (2010) and Kaneko et al. (2010).

Table 2

Financial return of different sources and rates of N fertilizer applied to maize crops in the 2016/2017 and 2017/2018 growing seasons. Campos Novos, Santa Catarina State, Brazil

Source	Rate	Cost of fertilizer (R$ ha^{-1})	Grain yield (kg ha^{-1})	Bags ha^{-1} (60 kg)	Selling price (R$ bag^{-1})*	OC (R$ ha^{-1})	GR (R$ ha^{-1})	OP (R$ ha^{-1})	PI (%)
					2016/2017				
C-UR	0	0	4162	69	23.47	2657.21	1628.04	−1029.17	−63.22
C-UR	140	334	11038	184	23.47	2657.21	4317.70	1326.49	30.72
C-UR	280	669	13099	218	23.47	2657.21	5123.89	1797.68	35.08
C-UR	420	1003	14457	241	23.47	2657.21	5655.10	1994.89	35.28
P-UR	0	0	4453	74	23.47	2657.21	1741.87	−915.34	−52.55
P-UR	140	840	8700	145	23.47	2657.21	3403.15	−94.06	−2.76
P-UR	280	1680	14058	234	23.47	2657.21	5499.02	1161.81	21.13
P-UR	420	2520	14319	239	23.47	2657.21	5601.12	423.91	7.57
UR-NI	0	0	4183	70	23.47	2657.21	1636.25	−1020.96	−62.4
UR-NI	140	642	9699	162	23.47	2657.21	3793.93	494.72	13.04
UR-NI	280	1285	13731	229	23.47	2657.21	5371.11	1428.9	26.6
UR-NI	420	1927	14132	236	23.47	2657.21	5527.97	943.76	17.07
					2017/2018				
C-UR	0	0	4184	70	35.70	2497.28	2489.33	−7.95	−0.32
C-UR	140	334	7609	127	35.70	2497.28	4527.21	1695.94	37.46
C-UR	280	669	10217	170	35.70	2497.28	6078.97	2912.69	47.91
C-UR	420	1003	11433	191	35.70	2497.28	6802.34	3302.06	48.54
P-UR	0	0	4507	75	35.70	2497.28	2681.81	184.53	6.88
P-UR	140	840	7885	131	35.70	2497.28	4691.58	1354.30	28.87
P-UR	280	1680	11355	189	35.70	2497.28	6756.37	2579.09	38.17
P-UR	420	2520	11722	195	35.70	2497.28	6974.44	1957.16	28.06
UR-NI	0	0	4207	70	35.70	2497.28	2502.87	5.59	0.22
UR-NI	140	642	9588	160	35.70	2497.28	5704.56	2565.28	44.97
UR-NI	280	1285	11900	198	35.70	2497.28	7080.5	3298.22	46.58
UR-NI	420	1927	13820	230	35.70	2497.28	8222.75	3798.47	46.19
UR-UI	0	0	4352	73	35.70	2497.28	2589.62	92.34	3.57
UR-UI	140	435	10094	168	35.70	2497.28	6005.78	3073.50	51.18
UR-UI	280	871	11433	191	35.70	2497.28	6802.78	3434.50	50.49
UR-UI	420	1306	11466	191	35.70	2497.28	6822.12	3018.84	44.25

C-UR, conventional urea; P-UR, protected urea; UR-NI, urea treated with nitrification inhibitor (DMPP); UR-UI, urea treated with urease inhibitor (NBPT); OC, operating cost; GR, gross revenue; OP, operating profit; PI, profitability index.
* Selling prices were collected in April 2017 and 2018.

In 2017/2018, the highest profitability index (51.2%) was obtained with the use of NBPT-treated urea at a rate of 140 kg N ha^{-1}. This combination of source and rate afforded a grain yield of 10,094 kg ha^{-1}. The second crop year had lower yields because of the drought that occurred during the vegetative phase of maize (Figure 1, Table 1). Despite this decrease in yield, there was a 34% increase in the price of 60 kg bags and a reduction in operating costs associated with the use of lower N rates (140 kg ha^{-1}). As a result, the profitability index was higher in the second agricultural year, particularly in treatments using low N rates.

Economic analysis allowed to infer that conventional and NBPT-treated urea, which have low market prices, afforded the best profitability indices. An important result is that NBPT-treated urea is an economically viable alternative for crop cycles with low water supply during vegetative development, as occurred in 2017/2018. Given that the price difference between both fertilizers is low (conventional urea = R$ 1.30 kg^{-1} and NBPT-treated urea = R$ 1.43 kg^{-1}) and that both have the same N content, the use of NBPT-treated urea is more economically profitable under high temperature and low humidity conditions, which favor losses by ammonia volatilization.

The analysis of the joint operating profits of both growing seasons (Figure 2B) shows that the maximum operating profit of conventional urea (R$ 2,665 ha^{-1}) was achieved with the use of 378 kg N ha^{-1}. For NBPT-treated urea, the maximum theoretical operating profit (R$ 2,499 ha^{-1}) was R$ 166 ha^{-1} lower than that of conventional urea, and it was achieved with the application of 278 kg N ha^{-1}. However, the maximum economic efficiency of treated urea was achieved by using a 26% lower N rate, possibly leading to significant environmental gains (Keeler et al., 2016; Gourevitch et al., 2018). The use of a lower N rate also decreases economic risks, given that the financial contribution to N fertilization is reduced. The maximum theoretical operating profits of DMPP-treated and sulfur-protected urea were R$ 2,515 ha^{-1} and R$ 1,561 ha^{-1}, respectively, estimated to be achieved with N rates of 341 and 308 kg ha^{-1}, respectively.

In treatments without N fertilization, the profitability index was equal to zero (Table 2). This result was due to the low yield of maize in the absence of N fertilization (Souza et al., 2012). Although sulfur-protected urea and DMPP-treated urea afforded grain yields similar to those obtained with other N sources, their operating profits were lower than that of conventional urea in both growing seasons (Figure 2). Such behavior can be attributed to the high price of these sources (sulfur-protected urea = R$ 2.72 kg^{-1}, DMPP-treated urea = R$ 2.88 kg^{-1}), higher than that of conventional N fertilizers.

Conclusions

The use of stabilized and protected urea as N fertilizers in maize crops grown on a Nitisol with clay texture afforded similar grain yields compared with conventional urea. The highest profitability indices were obtained with conventional urea and NBPT-treated urea. DMPP-treated and sulfur-protected urea provided similar grain yields to the other sources but were less profitable because of their high cost compared with that of conventional urea.

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