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Nitrogen fertilization of maize with enhanced-efficiency fertilizer

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Abstract

Urea fertilizers coated with polymers are used to optimize nitrogen (N) uptake by crops. However, there are many types of polymers that can be used for coating, leading to differences in observed results. Consequently, validation of this technology to guarantee its viability in agriculture is necessary. The objective of this study was to evaluate effects of ammonium- and nitrate-N levels in the soil, maize yield and nutritional status, N fertilization efficiency with Policote® urea coating, and different N doses under various soil and climatic conditions. Three field experiments were carried out to compare the performance of common urea with Policote® coated urea. A (2 x 4) + 1 factorial design with two N sources (common urea and Policote® coated urea), four N doses, and a control treatment (without N) was used. The results showed that Nitrate-N levels in the soil were not affected by the treatments. However, the ammonium-N levels was increased with N fertilization. Higher levels of soil ammonium-N contents were observed in treatments with Policote® coated urea. Foliar nitrogen levels were increased linearly with N doses only in one of the experiments. Nitrogen fertilization significantly increased maize yield. Higher yield and N fertilization efficiency were observed in treatments with Policote® coated urea than with common urea.

Keywords: Agronomic efficiency; Coated Fertilizer; Nitrogen; Policote®.

Introduction

Maize has great economic value as it is the most produced cereal in the world. Maize grain production for the 2016-17 season in Brazil hit 97,712.0 thousand tons harvested from 17,592.1 thousand ha at 5.6 t ha^{-1} (CONAB, 2017). However, the genetic potential of this crop exceeds more than 10 t ha^{-1}. Caires et al. (2016) observed maize yields above 19 t ha^{-1} under a long-term no-till cultivation system in Parana.

Maize requires high quantities of nitrogen (N), significantly increasing production costs. However, processes of N loss, such as volatilization, leaching, and denitrification, cause low N fertilization efficiency. Under inadequate N fertilization, maize presents low yields (Araújo et al., 2004; Amaral Filho, 2005; Cruz et al., 2008) because N plays an important role in biochemical processes in the plant (Sangoi et al., 2008; Silva et al., 2013; Frazão et al, 2014). Urea stands out from other N fertilizers due to its low N cost, high N concentration, widespread use, and high vulnerability to N loss through volatilization (Pereira et al., 2009). Thus, technologies aimed at improving the efficiency of this fertilizer are needed.

Enhanced-efficiency fertilizers (EEFs) have been developed to decrease nutrient losses and improve nutrient use efficiency by controlling the release of nutrients or stabilizing their chemical transformations in the soil. EEFs are classified as slow-release, controlled-release, or stabilized fertilizers. Slow-release and controlled-release fertilizers are defined as those containing compounds capable of chemically, physically, or microbiologically controlling the release rate of nutrients present in the fertilizer (Shaviv, 2005). Stabilized fertilizers, according to the Association of American Plant Food Control Officials (AAPFCO, 1997), are those containing any additives capable of inhibiting undesirable nutrient transformations in the soil. Therefore, EEFs may reduce N losses (mainly through volatilization and leaching) or affect the way this nutrient is available to the plants (ammonium- or nitrate-N).

The plant-available form of N is important because of the difference in metabolic energy expenditure between ammonium- and nitrate-N uptake (Grespan et al., 1998). It is known that cationic nutrients, such as ammonium-N, are absorbed passively without energy expenditure (Marschner, 1995), while anionic nutrients, such as nitrate-N, are absorbed with metabolic expenditure. About 45% of the ATP reserves in root hair cells may be used for the active uptake of anions such as nitrate-N (Carvalho et al., 2008).

Various polymers are used for urea coating. However, studies comparing polymer-coated urea with common urea have not led to conclusive results. Some reports point out the advantages of polymer-coated urea (Fan et al., 2004; Noellsch et al. 2009; Wilson et al., 2009; Pereira et al., 2009; Garcia et al., 2018), while others indicate its inefficiency, compared with common urea (Nelson et al., 2009, Cahill et al., 2010, Mckenzie et al., 2010, Civardi et al., 2011, Prando et al., 2013, Martins et al., 2014). Therefore, the type polymer coating has presumably some effects on yield of crops. Validation studies of EEFs with polymer coating are; thus, necessary to ensure the economic viability of these fertilizers. Therefore, the objective of this study was to evaluate ammonium- and nitrate-N levels in the soil, maize nutritional status, yield, and N fertilization efficiency in response to N doses and Policote® urea coating under various soil and climatic conditions.

Results and Discussion

Levels of nitrate- and ammonium-N in the soil

Levels of nitrate-N in the soil were not statistically influenced by the treatments, presenting an average value of 1.68 mg kg^{-1} of N-NO_3. Rainfall between the application of N fertilizers and the determination of soil nitrate-N content (94.7 mm, one week) possibly favoured nitrate leaching in 0–5 cm layer, which prevented detection of differences among the treatments. Ammonium-N content in the soil was linearly correlated ($p < 0.01$) with N fertilization (Figure 1A). Ammonium-N levels in treatments with common urea ranged from 3.43 to 29.6 mg kg^{-1} while in treatments with Policote® coated urea varied from 2.77 to 48.3 mg kg^{-1}. Policote® coated urea increased ammonium-N level in the soil by 53.5%, when compared with common urea (Figure 1B). Studying the adjustment of N doses based on soil and plant indicators in maize, Rambo et al. (2008) found ammonium-N levels in the soil between 7.6 and 27.5 mg kg^{-1}. In this work, ammonium-N levels in treatments with common urea were similar to those found by Rambo et al (2008). However, in treatments with Policote® coated urea, ammonium-N levels were higher than those cited by the same authors.

Leaf N levels

Significant differences in leaf N levels were only observed in the experiment in Londrina. The average leaf N content observed in experiments in Ponta Grossa and Santa Tereza do Oeste within the adequate range considered by Banihashemi et al. (2009) (i.e. 27–35 g kg^{-1} N) and above the adequate range in Londrina. According to Büll (1993), variations in foliar N levels in maize are caused by differences in genetic material, soil fertility, and changing weather conditions. A lack of response of foliar N content associated with increased maize yield to N fertilization was also reported by Martins et al. (2014). In the experiment in Londrina, foliar N content was significantly influenced ($p < 0.01$) only by N doses. There was a linear variation of leaf N content ($y = 35.73 + 0.0718*x$; $R^2 = 0.93$), which increased from 35.7 g kg^{-1} in the absence of N to 47.2 g kg^{-1} at 160 kg ha^{-1} N. Gomes et al. (2007) also observed a linear increase of N content in maize leaves in response to N doses. Kaneko et al. (2016) found that polymer-coated urea increased leaf N content in maize relative to conventional urea, but the authors report that this fact was caused by favourable environmental conditions that helped extract high amounts of N by plants.

Maize yield

Maize yields in experiments in Ponta Grossa, Londrina, and Santa Tereza do Oeste were statistically influenced by N doses ($p<0.05$; $p<0.01$, and $p<0.01$, respectively) and N sources ($p<0.05$, $p<0.01$, and $p<0.05$, respectively). Higher yields were observed in treatments with Policote® coated urea than with conventional urea in all experiments.

In Ponta Grossa (Figure 2A), the maximum yield with common urea was 13,290 kg ha^{-1} at 100 kg ha^{-1} N. The same yield was obtained using 48.5 kg ha^{-1} N of Policote® coated urea. The maximum maize yield with Policote® coated urea was 13,662 kg ha^{-1} at 71.7 kg ha^{-1} N.

In Londrina (Figure 2B), the maximum yield with common urea was 5,772.3 kg ha^{-1} at 87.5 kg ha^{-1} N. The same yield was obtained at 40.1 kg ha^{-1} N using Policote® coated urea. The maximum yield obtained with Policote® coated urea was 6,641.1 kg ha^{-1} at 100 kg ha^{-1} N. This represents an increase of 13.08% in grain yield relative to common urea and a 15% increase in grain yield relative to the control (without N).

In Santa Tereza do Oeste, the maximum maize yield with common urea was 9,323.9 kg ha^{-1} at 94.1 kg ha^{-1} N. The same yield was obtained using Policote® coated urea at 42.4 kg ha^{-1} N. The maximum yield of 9,628.0 kg ha^{-1} using Policote® coated urea was observed at 73.8 kg ha^{-1} N. Valderrama et al. (2014) observed maximum maize yield of 8,634 kg ha^{-1} at 120 kg ha^{-1} N, data similar to this study.

Using Policote® coated urea, only 48.5%, 45.8%, and 45.0% of common urea N dose was necessary to obtain the maximum maize yield in Ponta Grossa, Londrina, and Santa Tereza do Oeste, respectively. The low yields observed in Londrina may be explained by the low genetic potential of the maize cultivar used.

Contrary to what was observed in this work and by Fan et al. (2004), Noellsch et al. (2009), Pereira et al. (2009), Wilson et al. (2009), and Garcia et al. (2018), some studies reported no differences between conventional urea and polymer-coated urea (Nelson et al., 2009, Mckenzie et al., 2010, Civardi et al., 2011, Prando et al. et al., 2013). This may be explained by the wide variety of polymers used for urea coating. Therefore, effects of polymer-coated urea fertilizers should not be generalized, further reinforcing the need for validation of these technologies to ensure their viability in agriculture.

Nitrogen fertilization efficiency

Agronomic efficiency rates of nitrogen (AERs) are described in Table 1. AERs decreased with increasing nitrogen doses, which is consistent with the law of decreasing increments (Mitscherlich, 1909). The highest efficiency of N fertilization was observed in the experiment in Ponta Grossa, and the best agronomic efficiency of N fertilization was found in treatments with Policote® coated urea. The increased agronomic efficiency of Policote® coated urea explains higher yields obtained at the same N dose and the same yield at lower N doses when compared with common urea.

The same result (in this case maize yield) at a lower input dose is only possible when the input used is more efficient. An example of this is a comparison between limestone materials of different Effective Calcium Carbonate Equivalent (ECCE). The limestone with a higher ECCE value is used at a lower dose than limestone with a lower ECCE value (less efficient) to achieve the same soil neutralizing effect. Enhanced efficiency of N fertilizers is vital to improve crop yield and quality, reduction of N use, and maintaining soil, water, and air quality (Baligar et al., 2001).

Table 1. Agronomic efficiency indices (kg of maize harvested per kg of N applied) observed in experiments in Ponta Grossa (PG), Londrina (L), and Santa Tereza do Oeste (STO).

N doses kg ha^{-1}			Agronomic efficiency indices (kg kg^{-1})					
			Urea			Urea+Policote®		
PG	L	STO	PG	L	STO	PG	L	STO
25	20	30	51.8	45.1	16.6	104.3	69.7	19.6
50	40	60	52.4	24.0	15.5	66.1	28.2	25.4
75	80	120	36.0	22.7	11.4	46.6	35.0	13.7
100	160	180	34.7	9.1	6.7	33.3	14.0	7.0
Mean			43.7	25.2	12.5	62.6	36.7	16.4

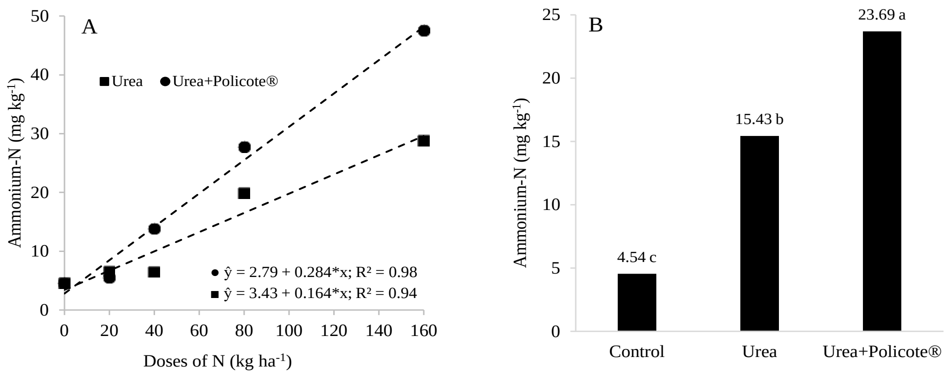

Fig 1. Soil ammonium-N content as a function of N rates and sources (A), and average soil ammonium-N contents as a function of N sources (B). *Significant at 5% by the *t*-test. (B) Ammonium-N levels in the soil as a function of N sources. Means followed by distinct letters differ by the Tukey test at 5%.

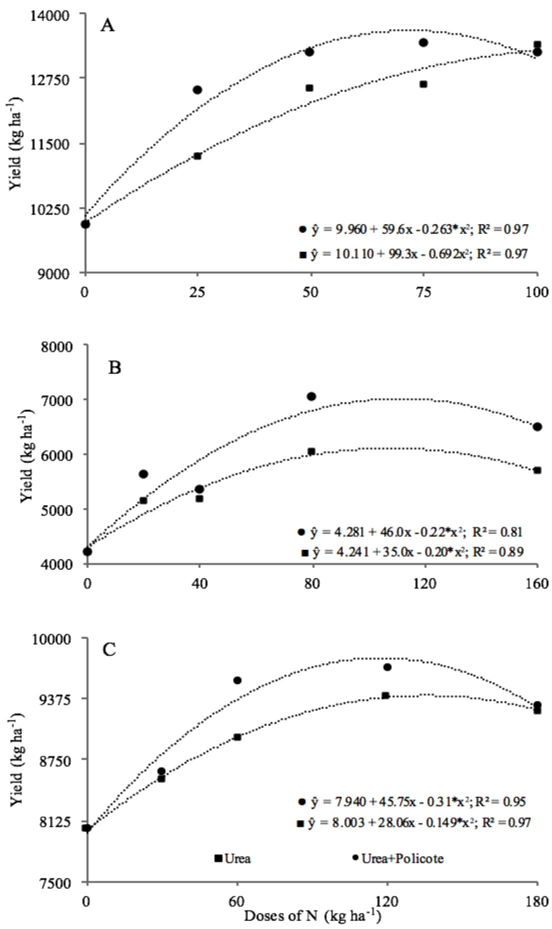

Fig 2. Maize yield in response to N doses and sources in Ponta Grossa, PR (A); Londrina, PR (B) and Santa Tereza do Oeste, PR (C).*Significant at 5% by the *t*-test.

Materials and Methods

Experimental design

Three field experiments were carried out. Each experiment had a (2 x 4) + 1 factorial design with the following treatments: two N sources (common urea - 45% N and Policote® coated urea - 42% N), four N doses, and a control treatment (without N). Policote® is an additive based on anionic water-soluble polymers distributed by Wirstchat Polímeros do Brasil. Treatments were surface-applied without any incorporation into the soil.

Each experimental plot had six rows with five meters long each. Four central rows were considered in this experiment and two guard rows were discarded. In all experiments, leaf N was determined by sampling the middle third of the leaf opposite and below the first ear at the flowering stage of maize. Samples were first oven-dried with forced air circulation at 70 °C until reaching constant mass and then ground. Subsequently, the samples were submitted to sulphur digestion and determination of N levels by the semi-micro Kjeldahl method (Carmo et al., 2000). Foliar N levels were compared with those considered suitable (27.5–35 g kg^{-1}) by Boaretto et al. (2009).

Yield data in each experiment were standardized to 13% moisture content.

Experiment in Ponta Grossa

This experiment was carried out on the experimental site of IAPAR, Ponta Grossa, Parana, Brazil using a randomized block design and four replications. The soil presented the following chemical characteristics (0–20 cm depth): pH ($CaCl_2$) = 5.50; C = 17.25 g dm^{-3}; P (Mehlich-1) = 12.23 mg dm^{-3}; K (Mehlich-1) = 1.2 $mmol_c$ dm^{-3}; Ca = 25.3 $mmol_c$ dm^{-3}; Mg = 15.0 $mmol_c$ dm^{-3}; H+Al = 31.8 $mmol_c$ dm^{-3}; V = 56.3%; clay = 201 g kg^{-1}; silt = 88 g kg^{-1}; sand = 711 g kg^{-1}

According to the Köppen classification, the climate in the experimental area is of Cfb type, humid, subtropical, with annual average temperatures below 21 °C, thermal amplitude between 9 °C and 13 °C, total annual precipitation between 1,300 and 1,800 mm, and well-distributed rainfall throughout the year (Caviglione et al 2000). The soil in the area was classified as Dystrophic Red Latosol (EMBRAPA, 2013).

Nitrogen doses used in this experiment were 25, 50, 75, and 100 kg ha^{-1}. The '30R50' hybrid was sown on 05 Nov 2010 with row spacing 0.8 m. The following fertilization scheme was implemented: 20 kg ha^{-1} N + 100 kg ha^{-1} P_2O_5 + 60 kg ha^{-1} K_2O using MAP (11% N and 52% P_2O_5) and KCl (60% K_2O) as sources. Twenty days after plant emergence, pelleted sulphur (90% S) was applied over the soil surface at a dose of 20 kg ha^{-1} S. Treatments were split into two applications carried out when plants had four and six leaves.

Experiment in Londrina

This experiment was carried out on the experimental site of IAPAR, Londrina, Parana, Brazil using a randomized block design and five replications. The soil had the following chemical characteristics (0–20 cm depth): pH ($CaCl_2$) = 4.90; P (Resin) = 16.5 mg dm^{-3}; K (Resin) = 0.41 $mmol_c$ dm^{-3}; Ca = 51.2 $mmol_c$ dm^{-3}; Mg = 25.0 $mmol_c$ dm^{-3}; H+Al = 66.8 $mmol_c$ dm^{-3}; V = 54.4%; clay = 150 g kg^{-1}; silt = 150 g kg^{-1}; sand = 700 g kg^{-1}.

Nitrogen doses used in this experiment were 20, 40, 80, and 160 kg ha^{-1}. The 'IPR 114' hybrid was sown on 03 Nov 2010 with row spacing of 0.8 m. The following fertilization scheme was adopted: 66 kg ha^{-1} P_2O_5 + 66 kg ha^{-1} K_2O using NPK 00:20:20 fertilizer. Treatments were applied as side-dressing when plants had six to eight developed leaves. Seven days after treatment applications, soil sampling (0–5 cm depth) was carried out along the sowing rows to determine ammonium- and nitrate-N levels in the soil. Shortly after that, obtained soil samples were dried in the oven (60 °C) for 2 hours. The extraction was done using a solution of K_2SO_4 (0.1 mol L^{-1}) and H_2SO_4 (0.05 mol L^{-1}), centrifugation, and filtering through a paper filter. The filtrate was split into two aliquots. One of the aliquots was used to determine ammonium-N content by salicylate blue spectrophotometry (Miyazawa et al., 1992). The other aliquot was used to reduce nitrogen with metallic zinc (0.1 g of metallic zinc per 5.0 mL of filtrate) and determine ammonium-N content as described above. Nitrate-N content was the difference between the two analyses.

Experiment in Santa Tereza do Oeste

This experiment was carried out on the experimental site of IAPAR, Santa Tereza do Oeste, Parana, Brazil using a randomized block design and four replications. The soil had the following chemical characteristics (0–20 cm depth): pH ($CaCl_2$) = 5.00; C = 35.84 g dm^{-3}; P (Mehlich-1) = 11.8 mg dm^{-3}; K (Mehlich-1) = 7.5 $mmol_c$ dm^{-3}; Ca = 85.0 $mmol_c$ dm^{-3}; Mg = 25.0 $mmol_c$ dm^{-3}; H+Al = 66.8 $mmol_c$ dm^{-3}; V = 56.3%; clay = 580 g kg^{-1}; silt = 100 g kg^{-1}; sand = 320 g kg^{-1}.

Nitrogen doses used in this experiment were 30, 60, 120, and 180 kg ha^{-1}. The '30F53H' maize hybrid was sown on 18 Nov 2010 with row spacing 0.9 m. The following fertilization scheme was adopted: 22.4 kg ha^{-1} N + 78.4 kg ha^{-1} P_2O_5 + 44.8 kg ha^{-1} K_2O using NPK 08:28:16 fertilizer. Treatments were applied when plants had four developed leaves. Together with the treatments, 30 kg ha^{-1} S was supplied using pelleted sulphur (90% S).

Statistical analysis

Obtained data were subjected to the analysis of variance and regression. Effects of N sources and doses were only analysed when there were statistically significant differences between treatments. The model with the highest coefficient of determination was chosen (R^2).

Statistical analyses were performed using the Assistat program (Silva and Azevedo, 2016). Average yields for N doses and sources and the efficiencies of N use by maize crop were calculated using the equation proposed by Fageria (2005).

Conclusions

Nitrate-N levels in the soil were not affected by the treatments. Ammonium-N levels in the soil increased with N fertilization. Higher soil ammonium-N contents were observed using Policote® coated urea than common urea. Nitrogen fertilization increased maize yields. Higher yields and N fertilization efficiency were observed with Policote® coated urea than with common urea.

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