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Yield, Quality Components, and Nitrogen Levels of Silage Corn Fertilized with Urea and Zeolite

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The zeolite and urea mixture may be use to improve nitrogen (N)–use efficiency of silage corn. The objective of this study was to evaluate dry-matter yield and nutritional levels of N of silage corn fertilized with urea and zeolite mixture. The experimental design was a 2 × 4 × 4 factorial randomized block design with three replications. Treatments included two types of stilbite zeolite (natural and concentrated), four levels of nitrogen (0, 50, 100, and 200 kg ha^{-1}), and four ratios of zeolite (25%, 50%, and 100% of N level). Treatments were applied 60 days after planting with the topdressing fertilization. The use of concentrated (650 g kg^{-1} of stilbite) or natural (470 g kg^{-1} of stilbite) zeolite with urea increased silage corn dry-matter production and leaf N concentrations.

Keywords Nitrogen, stilbite, Zea mays L

Introduction

Fertilization is one of the factors that most contribute to the increased dry-matter (DM) productivity of corn and also affects grain quality. Nitrogen (N) is an essential nutrient for corn growth and development. Several authors pointed out that increments in N fertilization increase corn DM yield. From a forage quality standpoint, N fertilization increased whole-plant crude protein concentration but effects on other forage quality variables were less consistent (Carlone and Russell 1987; O'Leary and Rehm 1990; Muchow and Sinclair 1994; Cox and Cherney 2001).

Urea has been the most used N source in Brazil (ANDA 2003), because of the lower cost per unit of N, but N-use efficiency (NUE) of urea may be decreased because of losses from the agricultural system. Nitrogen loss by volatilization of ammonia to atmosphere is one of the main factors responsible for low efficiency of urea applied on soil surface. This loss may reach extreme values, close to 80% of N applied (Lara-Cabezas, Korndörfer, and Motta 1997). Mulch may increase the amount of N lost by volatilization, especially when urea is applied on the soil surface.

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The N urea losses can be reduced using zeolites as additives in the fertilizers to control the retention and release of ammonium (NH_4^+) (Ming and Mumpton 1989; McGilloway et al. 2003; Gruener et al. 2003; Rehakova et al. 2004; Bernardi, Monte, and Paiva 2010). Zeolite minerals are crystalline hydrated aluminosilicates of alkali or alkaline-earth metals, structured in a three-dimensional rigid crystalline network, formed by the tetrahedral AlO_4 and SiO_4, which come together to compose a system of canals, cavities, and pores (Ming and Mumpton 1989; Gruener et al. 2003; Rehakova et al. 2004). There are more than 40 species of natural zeolites, of which clinoptilolite is apparently the most abundant, both in soils and in sediments (Ming and Dixon 1987). In Brazil, the largest zeolite reservoirs are found in the Parnaíba River Valley (Rezende and Angélica 1991), where the stilbite form of the heulandite group dominates (Monte et al. 2009).

These naturally occurring minerals have three main properties, which are of great interest for agricultural purposes: high cation exchange capacity, high water-holding capacity in the free channels, and high adsorption capacity. The main action of zeolite in ammonium conservation is a decrease in N concentration in soil solution through cation exchange. Besides retaining large quantities of ammonium ions, these minerals also interfere in the process of nitrification (Bartz and Jones 1983; Fergunson and Pepper 1987).

There are many reports in literature demonstrating the increased efficiency of N utilization when urea is used together with zeolite. Crespo (1989) showed, in a pot experiment with clinoptilolite, an increase around 130% of NUE, extraction, and DM yield of *Brachiaria decumbens*. Bouzo et al. (1994) increased productivity of sugarcane with utilization of 6 t ha^{-1} of zeolite in an Oxisol. Carrion et al. (1994) observed that the application of 150 kg ha^{-1} of urea coated with 5% to 10% of zeolite increased productivity of rice and tomato crops.

There are studies showing that zeolite reduced NH_4^+ losses from soil. Mackown and Tucker (1985) found that NH_4-clinoptilolite decreased nitrification process at about 11%. The decrease resulted from retention of NH_4^+ by clinoptilolite in places where nitrifying bacteria could not oxidize NH_4^+. He et al. (2002) achieved reductions of losses by ammonia volatilization when urea was applied with clinoptilolite.

Several indexes described in scientific agronomic research assess the efficiency of applied N (Novoa and Loomis 1981; Cassman et al. 1996). In field studies, these index calculations are based either on differences in crop yield and total N uptake by aboveground biomass of fertilized plots and an unfertilized control or on ^{15}N-labeled fertilizers to estimate crop and soil recovery of applied N (Dobermann 2007).

The objective of this study was to evaluate DM yield, quality components, and nutritional levels of N of silage corn fertilized with urea and zeolite mixture.

Materials and Methods

A 2-year field study was conducted at Embrapa Cattle Southeast, in Sao Carlos (22° 01′ S and 47° 54′ W; 856 m above sea level), State of Sao Paulo, Brazil. The climate is a Cwa type (Köeppen), with yearly average of low and high temperatures of 16.3 °C and 23.0 °C, respectively, and a total precipitation of 1502 mm, falling mostly in summer. Soil type was a Typic Hapludox, with the following chemical properties in the 0- to 0.2-m layer: $pHCaCl_2$ 5.5, organic matter 55 g dm^{-3}, P_{resine} 19 mg dm^{-3}, potassium (K) 7.0 $mmol_c$ dm^{-3}, calcium (Ca) 54 $mmol_c$ dm^{-3}, magnesium (Mg) 21 $mmol_c$ dm^{-3}, cation exchange capacity (CEC) 116 $mmol_c$ dm^{-3}, and base saturation 70%. The physical characteristics were 636 g kg^{-1} of sand, 40 g kg^{-1} of silt, and 324 g kg^{-1} of clay.

Zeolite used was collected in the northern part of the state of Tocantins, Brazil, in the basin of the Parnaiba River (Rezende and Angélica 1991) and had 470 g kg^{-1} of stilbite. According to the procedure described by Monte et al. (2009), the material was crushed and part of it was concentrated, separating contaminants (quartz and iron oxides and hydroxides) from zeolite by means of gravitational concentration, using the Humphrey spiral, resulting in material with 650 g kg^{-1} stilbite. Therefore, two types of zeolite were obtained: natural (470 g kg^{-1} of stilbite) and concentrated (650 g kg^{-1} of stilbite), both with particle size of <1 mm (16 mesh).

Irrigated corn (*Zea mays* L. cv. C577) was grown in a no-tillage system after fallow in both 2005–2006 and 2006–2007 crop seasons. The experiment was carried out in 16-m^2 plots, formed by sowing four 5-m-long rows, with a 0.8 m interlinear space, using five plants per meter. Experimental plots were fertilized uniformly at planting with 30 kg ha^{-1} of N, 100 kg ha^{-1} of phosphorus pentoxide (P_2O_5), 55 kg ha^{-1} of potassium oxide (K_2O), and 1.4 kg ha^{-1} of zinc (Zn).

The experiment was arranged in a 2 × 4 × 4 factorial randomized block design with three replications. Treatments included two types of stilbite (natural and concentrated), four levels of nitrogen (0, 50, 100, and 200 kg ha^{-1}), and four zeolite ratios (0%, 25%, 50%, and 100% of N level). Nitrogen source was urea. Treatments were applied 60 days after planting with the topdressing fertilization. Potassium was also applied in the total amount of 100 kg ha^{-1} of K_2O as potassium chloride (KCl). Corn ear leaves were sampled at the beginning of silking. Total concentration of N in leaf samples was determined after hot sulfuric digestion by a standard micro-Kjeldahl system (Nogueira and Souza 2005).

Silage corn harvest was initiated in March 2006 and 2007, when whole-plant water concentration was between 600 and 700 mg kg^{-1}. A minimum of two 4-m length rows was harvested per plot. Aliquots of corn samples were dried at 65 °C for 72 h for DM determination and then ground for quality component analyses. Plant material collected was evaluated for crude protein following Nogueira and Souza (2005), neutral detergent fiber, and acid detergent fiber following Souza et al. (1999), and in vitro organic-matter digestibility (Tilley and Terry 1963).

Nitrogen-use efficiency (NUE), agronomic efficiency (AE), crop recovery efficiency (RE), and physiological efficiency (PE) of applied urea N with zeolite were computed using the following formulae, as suggested by Dobermann (2007):

$$\mathrm{NUE} = \mathrm{Y_N F_N^{-1}}\ \text{(kg of harvest product per kg of N applied)},$$

$$\mathrm{AE} = (\mathrm{Y_N} - \mathrm{Y_0})\,\mathrm{F_N^{-1}}\ \text{(kg of yield increase per kg of N applied)},$$

$$\mathrm{RE} = (\mathrm{U_N} - \mathrm{U_0})\,\mathrm{F_N^{-1}}\ \text{(kg of increase in N uptake per kg of N applied)},$$

$$\mathrm{PE} = (\mathrm{Y_N} - \mathrm{Y_0})\ (\mathrm{U_N} - \mathrm{U_0})^{-1}\ \text{(kg of yield increase per kg of increase in N uptake from fertilizer)},$$

where

F_N is the amount of (fertilizer) N applied (kg ha^{-1}),
Y_N is the crop yield with applied N (kg ha^{-1});
Y_0 is the crop yield (kg ha^{-1}) in a control treatment with no N;
U_N is the total plant N uptake in aboveground biomass at maturity (kg ha^{-1}) in a plot that received N; and
U_0 is the total N uptake in aboveground biomass at maturity (kg ha^{-1}) in a plot that received no N.

Data of silage corn DM yield, quality compounds, and N leaf concentrations were tested for differences among treatments using a complete randomized block analysis of variance. Response function and equations were adjusted as a function of treatments. Where appropriate, the Tukey test was used for determining differences between means.

Results and Discussion

All results presented in this study refer to a time scale of two cropping seasons: 2005–2006 and 2006–2007. Dry-matter yield of silage corn as a function of N fertilizer level and zeolite ratio and type is illustrated in Figure 1. The greatest DM yields (14.5 and 14.1 t ha^{-1}) were obtained with 183 and 161 kg ha^{-1} of N and with 59.6% and 42.2% of concentrated and natural zeolite, respectively. The higher levels of urea N necessary for greater DM yield with concentrated zeolite indicated an adsorption of the NH_4 cation (Mackown and Tucker 1985).

These values are approximately 48% greater than those obtained without N fertilizer and only 5.5% and 3.6% greater than DM yield obtained with N fertilizer but without concentrated or natural zeolite. Nitrogen improves biomass production because it promotes a faster photosynthetic rate by an increase in crop radiation interception and in conversion efficiency into biomass (Novoa and Loomis 1981). Results are consistent with those observed by O'Leary and Rehm (1990), Muchow and Sinclair (1994), and Cox et al. (1993). These results confirms those reports from Ming and Mumpton (1989), McGilloway et al. (2003), Gruener et al. (2003), and Rehakova et al. (2004). Results agree with those obtained by Crespo (1989), Bouzo et al. (1994), Carrion et al. (1994), and Bernardi et al. (2010), who also found beneficial effects when using this mineral together with urea.

Maximum N concentrations observed were 34 and 31 g kg^{-1} achieved with 199 and 165 kg ha^{-1} of N and 65% and 54% of natural or concentrated zeolite, respectively (Figure 2). These values are 46% and 41% greater than those of the control and 33% and 28% greater than those without zeolite but with the same N fertilizer level. The principle of foliar diagnosis is based on comparing nutrient concentrations in leaves with standard values. Crops are considered to integrate factors such as presence and availability of soil mineral N, weather variables, and crop management. Leaves are associated with metabolic activity, such as photosynthesis and high N (Plénet and Lemaire 2000). The range of levels considered adequate for N in corn leaves is between 27 and 40 g kg^{-1} (Jones, Wolf, and

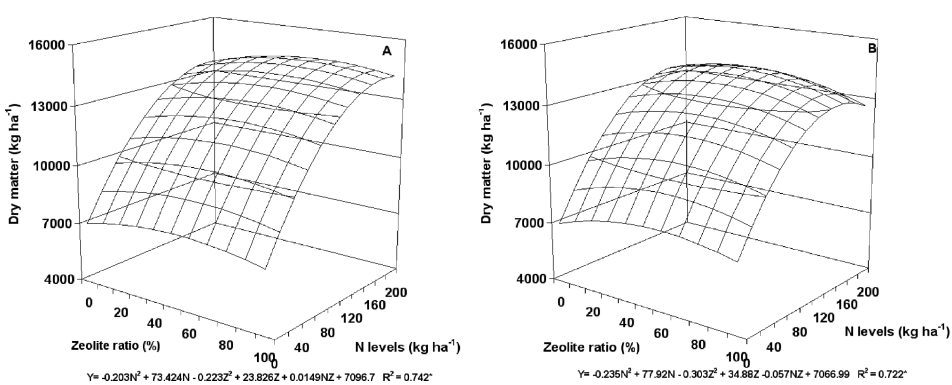

Figure 1. Silage corn dry-matter yield according to level of urea N and ratio of concentrated (A) and natural (B) zeolite.

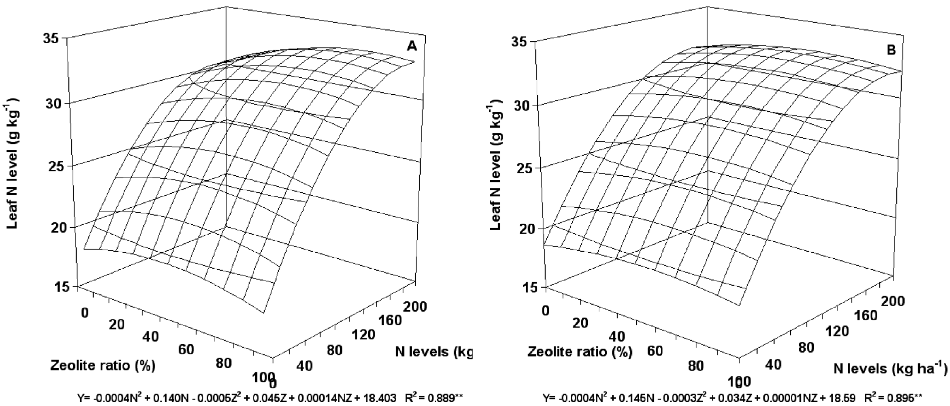

Figure 2. Silage corn N levels in ear leaf according to level of urea N and ratio of concentrated (A) and natural (B) zeolite.

Mills 1991). Thus, the maximum values (between 34 and 31 g kg^{-1}) obtained were considered adequate. Nitrogen fertilization levels lower than 83 and 78 kg ha^{-1} with concentrated and natural zeolite, respectively, lead to insufficient N leaf concentration ($<$27 g kg^{-1}).

Moreover, the relationship between nutrient concentration and crop yield forms the basis for the utilization of plant analysis to assess plant nutrient status. Dry-matter production and leaf N levels showed a positive correlation (Figure 3), where yield increased with increasing N concentration. Other experiments on the response of corn to N applications have shown positive relationships between yields and total N concentration of the ear leaf around anthesis (Cerrato and Blackmer 1991; Plénet and Lemaire 2000).

Crude protein values increased linearly ($P < 0.05$) with increasing N fertilizer levels, and N uptake was greater with 192 kg ha^{-1} of N, but there were no differences between zeolite ratios (Figure 4). Results showing that N fertilization increased whole-plant CP concentrations were reported by Cox et al. (1993), O'Leary and Rehm (1990), and Cox and Cherney (2001).

There was no statistical difference between nutritional quality characteristics of silage corn according to N fertilizer levels and natural or concentrated zeolite ratios (Table 1). O'Leary and Rehm (1990), Cox and Cherney (2001), and Sheaffer, Halgerson, and Jung (2006) also reported that increasing N fertilization effects on silage corn quality

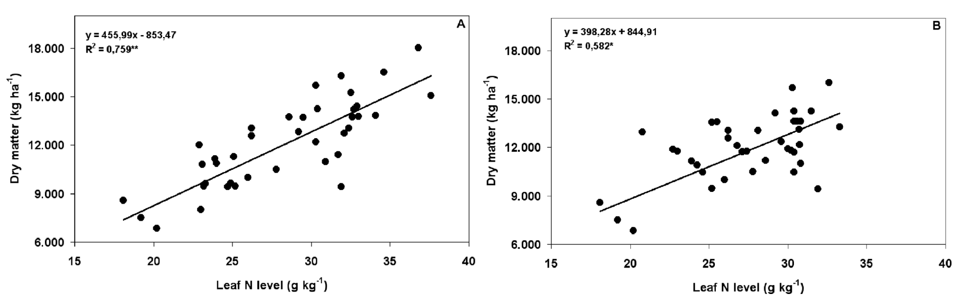

Figure 3. Silage corn dry-matter yield as a function of N foliar levels affected by concentrated (A) and natural (B) zeolite.

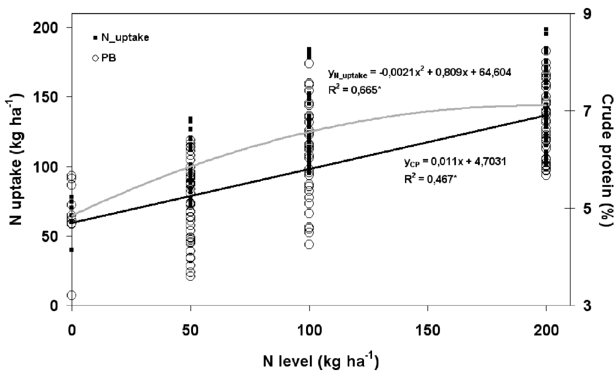

Figure 4. Silage corn total N uptake in aboveground biomass at maturity and crude protein according to urea N levels.

Table 1
Silage corn neutral detergent fiber (NDF), acid detergent fiber (ADF), and in vitro digestibility of organic matter (IVOMD) according to level of urea N and ratio of concentrated and natural zeolite

Zeolite ratio (%)	NDF (kg ha^{-1} of N)				ADF (kg ha^{-1} of N)				IVOMD (kg ha^{-1} of N)			
	0	50	100	200	0	50	100	200	0	50	100	200
Natural zeolite												
0	54.0	52.0	52.3	50.5	22.5	26.5	24.5	26.0	69.8	66.5	67.4	66.0
25	50.2	58.7	53.5	54.0	25.2	26.9	26.4	28.0	68.5	65.3	66.5	66.2
50	49.0	52.5	55.4	49.7	26.1	23.5	27.5	23.9	68.0	66.5	65.9	66.4
100	52.8	53.8	47.4	55.7	24.3	26.5	22.9	28.8	69.3	66.7	71.2	66.0
Concentrated zeolite												
0	54.0	54.5	53.8	57.8	22.5	27.2	27.8	30.0	69.8	68.3	67.5	67.8
25	50.2	52.1	52.3	53.3	25.2	26.5	25.1	26.0	68.0	67.2	67.4	67.5
50	49.0	52.0	51.9	51.0	26.1	26.3	24.5	24.5	68.5	66.5	67.3	66.0
100	52.8	50.7	51.9	50.5	23.4	25.2	24.4	24.1	69.3	66.3	67.1	65.6

Note. Values were not significantly different according to Tukey's test ($P < 0.05$).

components were inconsistent. In contrast, Cox et al. (1993) reported that in a 2-year field study silage quality increased linearly as N rate increased from 0 to 200 kg ha^{-1} of N.

The ratio of DM yield to the amount of applied N (NUE) declined with increasing N application rates (Table 2), as already shown by Novoa and Loomis (1981) and Cassman et al. (1996). The greater yields at low levels of N supply are because this nutrient is the primary factor limiting growth. As N supply increases, yield increase becomes smaller, because yield determinants are other than that limiting nutrient. Considering the ratio of zeolite, there were no significant differences in NUE except at the lowest level of N (50 kg ha^{-1}), at which 50% of natural zeolite provided the greatest NUE.

Nitrogen-use efficiency is also called the partial factor of productivity of applied N, which is an aggregate efficiency index that includes contributions to crop yield

Table 2

Silage corn nitrogen-use efficiency (NUE), agronomic efficiency (AE), crop recovery efficiency (RE), and physiological efficiency (PE) according to level of urea N and ratio of concentrated and natural zeolite

	NUE (kg ha^{-1} of N)			AE (kg ha^{-1} of N)			RE (kg ha^{-1} of N)			PE (kg ha^{-1} of N)		
Zeolite ratio (%)	50	100	200	50	100	200	50	100	200	50	100	200
Natural zeolite												
0	197.2*Ab*	133.1*B*	62.2*C*	46.6*ABb*	57.8*A*	24.5*B*	0.68*b*	0.59	0.35	72.3*b*	108.8	69.3
25	224.4*Aab*	126.0*B*	73.2*C*	73.8*Aab*	50.7*B*	35.5*B*	0.63*b*	0.66	0.41	120.7*a*	91.6	95.6
50	242.7*Aa*	131.8*B*	67.7*C*	92.1*Aa*	56.5*B*	30.1*C*	1.21*Aa*	0.60*B*	0.41*B*	76.8*b*	101.8	74.1
100	225.8*Aab*	115.7*B*	62.9*C*	75.2*ab*	40.4	25.3	0.99*Aab*	0.53*B*	0.32*B*	76.7*b*	82.2	91.1
Concentrated zeolite												
0	197.2*A*	133.1*B*	62.2*C*	46.6*AB*	57.8*A*	24.5*B*	0.62	0.59	0.35	92.3	108.8	69.3
25	214.6*A*	132.4*B*	75.5*C*	64.0	57.1	37.9	0.66	0.58	0.48	100.0	104.7	88.6
50	213.5*A*	127.2*B*	76.2*C*	62.9	51.9	38.5	0.60	0.64	0.45	130.1	81.2	91.7
100	206.6*A*	138.5*B*	67.2*C*	56.0*AB*	63.2*A*	29.6*B*	0.33	0.63	0.41	197.8	122.1	79.3

Note. Values followed by different letters are significantly different according to Tukey's test ($P < 0.05$) among N level (uppercase) and zeolite ratio (lowercase).

derived from uptake of indigenous soil N, N fertilizer uptake efficiency, and efficiency of conversion of N acquired by plants to DM yield (Cassman et al. 1996).

Agronomic efficiency is the product of the efficiency of N recovery from applied N sources, physiological efficiency is the efficiency with which the plant uses each unit of N acquired from applied N to produce grain, and crop recovery efficiency represents the degree of congruence between plant N demand and available supply of N from applied fertilizer (Dobermann 2007). However, results also showed that there were no statistical differences among treatments in agronomic efficiency, physiological efficiency, and recovery efficiency (Table 2). Nitrogen-use efficiency is a variable more sensitive to variations in fertilizer treatments than the others. Despite the recommendation of Dobermann (2007) to assess causes of variation with NUE, agronomic research on N fertilizer efficiency should include measurements of other indexes.

Considering the economics of zeolite urea use, results indicated that the high proportion of zeolite required to provide the relatively small effect on increasing the DM yield (because of the reduction of losses) may be a limiting factor for achieving the commercial use of this mineral. Eyde and Holmes (2006) reported that prices of zeolite for agricultural or industrial use in the United States ranged from $30 to $70 per ton of coarse-size products (below 40 mesh). The mixture of both should be interesting only when the price of the mineral is lower than increases in the 4–6% increase in productivity obtained with zeolite and urea.

Conclusions

The use of 62% and 48% of concentrated or natural zeolite with urea increased silage corn DM production and provided the best use of N at the higher doses of fertilizer.

There were no significant differences between levels of fertilization and quality compounds: neutral detergent fiber, acid detergent fiber, and in vitro digestibility. Crude protein increased linearly with N fertilization levels.

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