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The Proceedings of the International Plant Nutrition Colloquium XVI

Title
Yield, quality components and nitrogen levels of silage corn fertilized with urea and zeolite

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Publication Date
2009-07-01

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Introduction

Nitrogen fertilization is one of the factors that contributes most to the increased DM productivity and quality of corn. Urea nitrogen has been the most used N-source in Brazil (Anda, 2003), due to lower cost per unit of N. But N use efficiency of urea may be reduced because of losses from agricultural system by volatilization of ammonia to atmosphere. This is one of the main factors responsible for the low efficiency of urea, and may reach extreme values, close to 80% of N applied (Lara Cabezas et al., 1997), even so in acid soils, since the liming increases soil pHs and favors volatilization. Mulch form no-tillage system may also increase the amount of N lost by volatilization, especially when urea is applied on soil surface.

The N-urea losses can also be reduced using zeolites as additives in the fertilizers to control the retention and release of NH_4^+. There are several reports in the literature showing that the addition of zeolite to the source of N can improve the nitrogen use efficiency (Ming and Mumpton, 1989; McGilloway et al., 2003; Gruener et al., 2003; Rehakova et al., 2004). Zeolite minerals are crystalline hydrated aluminosilicates of alkali or alkaline-earth metals, structured in 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). 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 ion, these minerals also interfere with the process of nitrification (Bartz and Jones, 1983; Fergunson and Pepper, 1987).

There are many reports in the 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 of around 130% in N use efficiency, N uptake and dry matter yield of *Brachiaria decumbens*. Bouzo et al. (1994) increased productivity of sugar cane 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 also studies showing that zeolite reduce NH_4^+ losses from soil. Mackown and Tucker (1985) found that NH_4-clinoptilolite decreased nitrification with 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. While zeolites are useful for increasing N use efficiency in a range of crops, no information exists on the degree to which they might enhance N use efficiency in agricultural systems where urea-N is used to fertilized corn, especially on acid soils. The objective of this study was to evaluate dry matter yield, quality components and nutritional levels of nitrogen of silage corn fertilized with urea and zeolite mixture.

Materials and methods

A two-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 Cwa type (Köeppen), with yearly average of low and high temperatures of 16.3 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 0-0.2 m layer: $pHCaCl_2$ = 5.5, organic matter = 55 g dm^{-3}, P_{resine} = 19 mg dm^{-3}, K = 7.0 $mmol_c$ dm^{-3}, Ca = 54 $mmol_c$ dm^{-3}, Mg = 21 $mmol_c$ dm^{-3}, CEC = 116 $mmol_c$ dm^{-3} and basis saturation = 70%; and the physical characteristics: 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 North of State of Tocantins, Brazil, in the basin of the Parnaiba river. It had 470 g kg^{-1} of stilbite. 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 the 2005–2006 and 2006–2007 growing seasons. The experiment was carried out in 16-m^2 plots, formed by four sowing rows of 5-m length, 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 P_2O_5, 55 kg ha^{-1} of K_2O and 1.4 kg ha^{-1} of Zn.

The experiment was arranged in a 2×4×4 factorial randomized block design with three replications. Treatments comprised 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). Zeolite was mixed with urea and recovered its granules. 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 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 dry matter determination and than ground for quality component analyses. Plant material collected was evaluated for crude protein (CP), following Nogueira and Souza, 2005), neutral detergent fiber (NDF) and acid detergent fiber (ADF) 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):

$$NUE = Y_N F_N^{-1} \text{ (kg of harvest product per kg of N applied)},$$
$$AE = (Y_N - Y_0) F_N^{-1} \text{ (kg of yield increase per kg of N applied)},$$
$$RE = (U_N - U_0) F_N^{-1} \text{ (kg of increase in N uptake per kg of N applied)},$$
$$PE = (Y_N - Y_0)(U_N - U_0)^{-1} \text{ (kg of yield increase per kg of increase in N uptake from fertilizer)},$$

wherein

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

Data of silage corn dry matter yield, quality compounds and nitrogen 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, 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 highest DM yields (14.5 and 14.1 t ha^{-1}) were obtained respectively with 183 kg ha^{-1} of N plus 59.6% of concentrated zeolite and 161 kg ha^{-1} of N and with 42.2% of natural zeolite. The higher levels of urea-N necessary for higher DM yield with concentrated zeolite indicates an adsorption of the NH_4^+ cation (Mackown and Tucker, 1985).

The highest values of DM yields were approximately 48% higher than those obtained without nitrogen fertilizer, and only 5.5% and 3.6% higher than DM yield obtained with N fertilizer but without concentrated or natural zeolite. Nitrogen improves biomass production because it promotes a higher photosynthetic rate by an increase in crop radiation interception and in conversion efficiency into biomass (Novoa and Loamis, 1981). Results are consistent with those observed by Carlone and Russell (1987), O'Leary and Rehm (1990), Muchow and Sinclair (1994) and Cox et al. (1993). These results confirms those repots from Ming and Mumpton (1989), McGilloway et al. (2003), Gruener et al. (2003) and Rehakova et al. (2004) and also indicate that zeolite minerals are able to contribute to increasing N uptake through the control of retention of ammonium ion–formed by urea hydrolysis in the soil, due to zeolite high cation exchange capacity and ammonium withdrawal from soil solution (Bartz and Jones, 1983; Ferguson and Pepper, 1987). Results agree with those obtained by Crespo (1989), Bouzo et al. (1994), Carrion et al. (1994) and He et al. (2002), who also found beneficial effects when using this mineral together with urea.

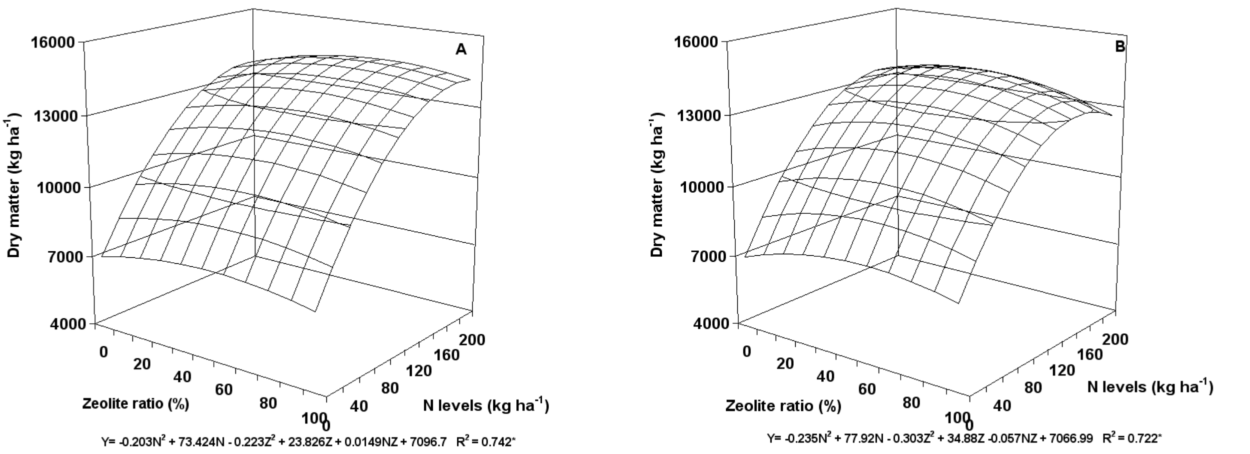

Figure 1. Silage corn dry matter yield according to level of urea-N and ratio of concentrated (A) and natural (B) zeolite. Results are average of two crop seasons.

Maximum leaf 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% higher than those of the control and 33% and 28% higher 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 nitrogen (Plénet and Lemaire, 2000). The range of levels considered adequate for N in corn leaves is between 27 and 40 g kg^{-1} (Jones Jr. et al., 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).

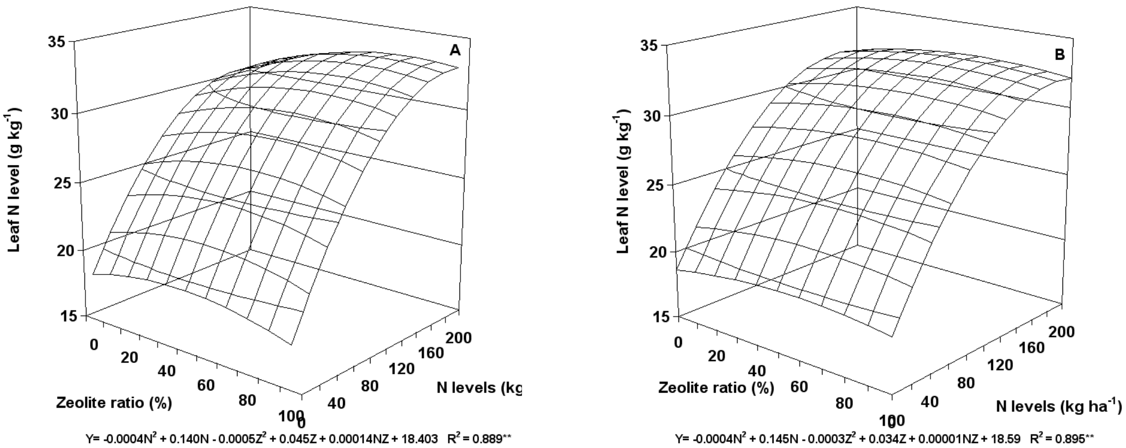

Figure 2. Silage corn nitrogen levels in ear leaf according to level of urea-N and ratio of concentrated (A) and natural (B) zeolite. Results are average of two crop seasons.

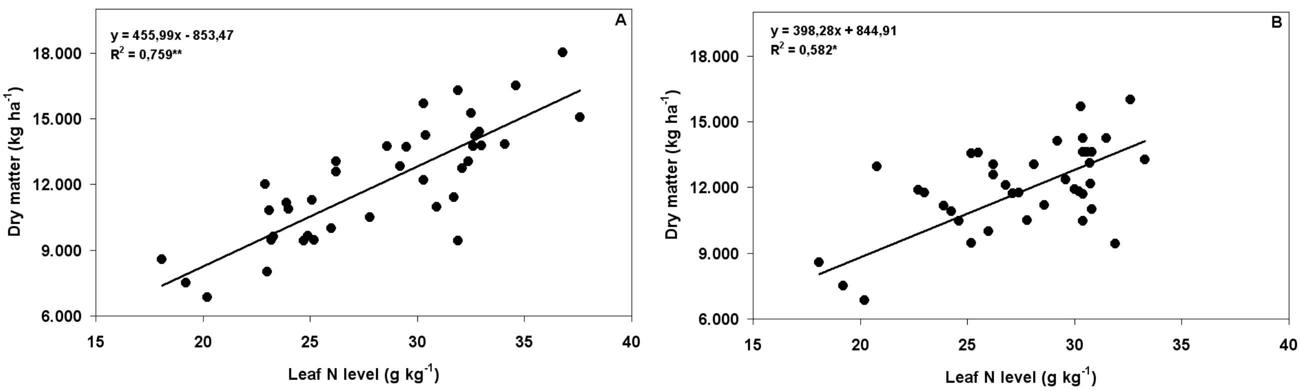

Figure 3. Silage corn dry matter yield as a function of N foliar levels affected by of concentrated (A) and natural (B) zeolite. Results are average of two crop seasons.

Crude protein values increased linearly ($P<0.05$) with increasing N fertilizer levels, and N uptake was higher 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. O'Leary and Rehm (1990), Cox and Cherney (2001) and Sheaffer et al. (2006) also reported that increasing N fertilization effects on silage corn quality components were inconsistent. In contrast, Cox et al. (1993) reported that in a two-year field study silage quality increased linearly as N rate increased from 0 to 200 kg ha^{-1} of N.

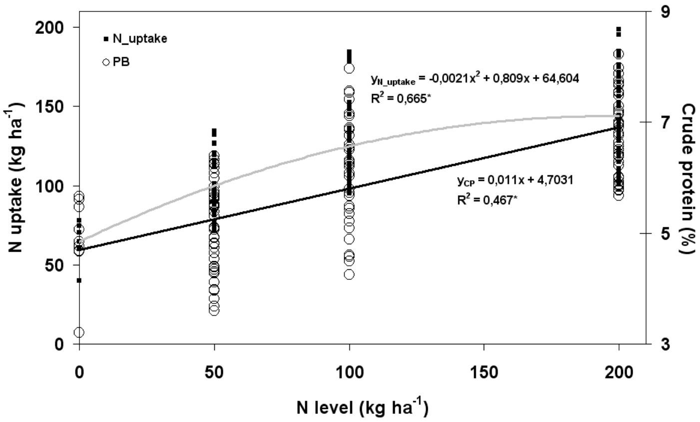

Figure 4. Silage corn total N uptake in aboveground biomass at maturity and crude protein according to urea-N levels. Results are average of two crop seasons.

The ratio of DM yield to the amount of applied N (NUE) declined with increasing N application rates (Table 1), as already shown by Novoa and Loamis (1981) and Cassman et al. (1996). The higher yields at low levels of nitrogen supply are due to the fact that this nutrient is the primary factor limiting growth. As nitrogen 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 nitrogen (50 kg ha^{-1}), at which 50% of natural zeolite provided the highest NUE. The results of agronomic efficiency also showed that there were no statistical differences between treatments in AE, PE and RE (Table 1). Nitrogen use efficiency is a variable more sensitive to variations in fertilizer treatments than AE, PE and RE. 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.

Table 1. 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. Results are average of two crop seasons.

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

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

Considering the economics of zeolite-urea use, results indicated that the high proportion of zeolite required to provide the relatively small effect on the DM yield increasing, due the reduction of losses, can be a limiting factor and may be a limiting factor for achieving the commercial use of this mineral. Nevertheless, Eyde and Holmes (2006) reported that prices of zeolite for agricultural or industrial use in U.S.A. ranged from 30 to 70 dollars per tonne of coarse size products (below 40 mesh). Besides the reduction in N concentration of zeolite-urea of a new fertilizer, the mixture of both should be interesting due the low price of the mineral comparing with urea prices. Actually the urea cost in Brazil is around 450 dollars per tonne, considering a medium price of 50 dollars per tonne of zeolite, the mixture should be interesting. Since the cost of zeolite-urea that give the higher DM yield should be just 2 or 3% higher than the cost of applying pure urea, else leading to increases in productivity of 4 to 6%.

Conclusion

The use of 62% and 48% of concentrated or natural zeolite with urea increased silage corn dry matter 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: NDF, ADF and *in vitro* digestibility. But crude protein increased linearly with N fertilization levels.

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