Can Zeolite Application Decrease the Need for Nitrogen in Silage Corn?

Zeynep Gül¹ • Mustafa Tan² • Halil Yolcu³
¹Atatürk University, Plant Production Application and Research Center, Erzurum/Turkey
²Trakya University, Havsa Vocational School, Edirne/Turkey
³Gümüşhane University, Kelkit Aydin Doğan Vocational Training School, Gümüşhane/Turkey

ABSTRACT

The effects of applications of zeolite, nitrogen and zeolite + nitrogen on yield, quality and some morphological traits of silage corn was researched at the Research Station of the Agriculture Faculty, University of Ataturk, Eastern Turkey, during 2012 and 2013. Treatments included a control, three zeolite (Z¹: 500, Z²: 1000, Z³: 1500 kg ha⁻¹), three nitrogen (N¹: 50, N²: 100, N³: 150 kg ha⁻¹) and nine combinations of zeolite + nitrogen. The experimental design was randomized complete blocks with three replications. The application of zeolite + nitrogen application enhanced silage yield by 5.8-18.9%, dry matter yield by 4.5-21.4%, corncob rate by 6.6%, plant height by 3.0-16.1% and leaf rate by 17.5%. Further, the application of zeolite + medium or low nitrogen application produced similar silage yield, dry matter yield, dry matter rate, crude protein content, ADF, NDF, corncob rate, stem rate, plant height and leaf rate in comparison to the highest level nitrogen application. The results indicate that the application of zeolite + nitrogen can be used to increase efficiency of nitrogen and to decrease nitrogen requirements in silage corn for yield and other parameters.

Introduction

In the Eastern Mediterranean regions, forage crops production areas are insufficient, as farmers prefer to grow cereal and other crops in their fields (Yolcu et al. 2009a). Subsidies given for forage production by the government to meet feed requirements led to an increase in forage production areas in Turkey in recent years (Yolcu et al., 2009b). Farmers receiving subsidies began cultivating silage corn and other forage crops (Yolcu and Tan, 2008). Silage corn is used in feed for growing animals, dry cows and lactating cows (Yolcu and Cetin, 2015) and it is an important feed source due to its high yield, energy and quality (Turgut, 2002).

Nitrogen is an essential nutrient for silage corn (Sheaffer et al., 2006; Islam and Garcia, 2014) and it is the most limiting factor in terms of yield for silage corn cultivation (Safdarian et al., 2014). Increasing nitrogen doses has a positive effect on yield and quality properties of silage corn (Safdarian et al., 2014; Kaplan et al., 2016). However, intensive nitrogen use increases nitrate pollution in ground water and environmental problems caused by using large amounts of nitrogen have been detected in many areas in the European Union (Berenguer et al., 2008). Improving N efficiency (Masoero et al., 2011; Gholamhosseini et al., 2013) and reducing excess N fertilization for sustainable agricultural practices (Masoero et al., 2011) are techniques used to address these problems.

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Zelelite is commonly used in many studies to contribute to sustainable agricultural practices (Yolcu, 2011; Yolcu et al., 2011; Gholamhoseini et al., 2013; Gul et al., 2015). Zeolite is a hydrated aluminosilicate (Isildar, 1999; Torma et al., 2014) characterized by three-dimensional networks of SiO₄ and AlO₄ tetrahedral, which are linked by sharing all oxygen atoms, then the partial substitution of Si⁴⁺ by Al³⁺ lead to high levels of negative charge that is compensated by alkali and earth alkaline cations (Rehakova et al., 2004). Zeolite has high cation exchange capacity and surface area (Kithome et al., 1999). It can increase the ratio of N uptake and reduce N leaching (Malekian et al., 2011). Its ion-exchange properties can be used to adsorb NH₄⁺ (Kithome et al., 1999).

Silage corn may be fertilized by the application of zeolite + nitrogen to decrease the requirement for nitrogen owing to nitrogen adsorption ability of zeolite. The objective of this study was conducted to determine the effects of applications of zeolite, nitrogen and zeolite + nitrogen applications on silage yield, dry-matter yield, dry matter rate, crude protein content, ADF, NDF, corn cob rate, stem rate, plant height and leaf rate of silage corn.

Materials and Methods

Field Experiment and Growth Conditions

The experiment was conducted at the Research Station of the Agriculture Faculty, University of Ataturk, Eastern Turkey (39° 55'N and 41°61'E, elevation 1869 m). Winters are cold and snowy and summers are cool and dry in the research location. Autumn and spring are short and winters are long. Detailed climatic data is shown in Table 1.

Table 1. Mean temperature and precipitation in 2012, 2013 and long-term (1960-2013) in Erzurum

| Months    | 2012  | 2013  | Long-term | 2012  | 2013  | Long-term |
|-----------|-------|-------|-----------|-------|-------|-----------|
| May       | 11.4  | 11.6  | 10.6      | 73.0  | 32.3  | 67.2      |
| June      | 15.7  | 15.0  | 14.9      | 7.0   | 25.1  | 45.2      |
| July      | 19.0  | 19.4  | 19.3      | 19.8  | 7.8   | 25.9      |
| August    | 20.0  | 19.5  | 19.3      | 22.8  | 5.2   | 16.8      |
| September | 15.0  | 13.6  | 14.5      | 11.0  | 11.5  | 20.5      |
| Mean/Total| 15.5  | 15.8  | 15.7      | 133.6 | 81.9  | 157.6      |

*The data was obtained from Erzurum Regional Directorate of Meteorology.

Table 2. Treatments for applications of zeolite, nitrogen and additions of zeolite to nitrogen

| Treatments                  |
|-----------------------------|
| Control                     | no zeolite and nitrogen |
| Z₁                          | 500 kg ha⁻¹ zeolite     |
| Z₂                          | 1000 kg ha⁻¹ zeolite    |
| Z₃                          | 1500 kg ha⁻¹ zeolite    |
| N₁                          | 50 kg ha⁻¹ nitrogen     |
| N₂                          | 100 kg ha⁻¹ nitrogen    |
| N₃                          | 150 kg ha⁻¹ nitrogen    |
| N₁Z₁                        | 50 kg ha⁻¹ nitrogen + 500 kg ha⁻¹ zeolite |
| N₁Z₂                        | 50 kg ha⁻¹ nitrogen + 1000 kg ha⁻¹ zeolite |
| N₁Z₃                        | 50 kg ha⁻¹ nitrogen + 1500 kg ha⁻¹ zeolite |
| N₂Z₁                        | 100 kg ha⁻¹ nitrogen + 500 kg ha⁻¹ zeolite |
| N₂Z₂                        | 100 kg ha⁻¹ nitrogen + 1000 kg ha⁻¹ zeolite |
| N₂Z₃                        | 100 kg ha⁻¹ nitrogen + 1500 kg ha⁻¹ zeolite |
| N₃Z₁                        | 150 kg ha⁻¹ nitrogen + 500 kg ha⁻¹ zeolite |
| N₃Z₂                        | 150 kg ha⁻¹ nitrogen + 1000 kg ha⁻¹ zeolite |
| N₃Z₃                        | 150 kg ha⁻¹ nitrogen + 1500 kg ha⁻¹ zeolite |

Soil in the research site was inadequate in terms of nitrogen (0.05%), available phosphorus (67 kg ha⁻¹ P₂O₅), lime (4.1% CaCO₃) and organic matter (0.97%) but rich in potassium (1740 kg ha⁻¹) and pH was 6.8. In the second year of this research, another part of this field was used with similar soil characteristics. Three levels of nitrogen, zeolite and nine combinations of zeolite and nitrogen (Table 2) were applied to silage corn plots to determine the effects on silage yield (SY), dry matter yield (DMY), dry matter rate (DMR), crude protein content (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), corn cob rate, stem rate, plant height and leaf rate during 2012 and 2013. The experimental design was randomized complete blocks with three replications.

Each plot of the trial consisted of five rows spaced at 70 cm intervals (Kara, 2006) and each row was 4 m long. Each plant was spaced 15-20 cm distance (Kara, 2006) in each row. Nitrogen fertilizer was applied twice; half of this during the seedbed preparation and the other half when the corn plant reached 40-50 cm in each plot in each year. Ammonium sulfate [(NH₄)₂SO₄] was used in this research as a nitrogen fertilizer. Zeolite, which we used in the previous study, were pH: 4.2, organic matter: 14.2%, humic acid + fulvic acid: 40%, N: 0.16%, P: 0.04%, K: 0.32, S: 1.20%, Ca: 6500 mg kg⁻¹, Mg: 1800 mg kg⁻¹, Na: 1420 mg kg⁻¹, Fe: 192 mg kg⁻¹, Mn: 65 mg kg⁻¹, Zn: 224 mg kg⁻¹ and Cu: 45 mg kg⁻¹ (Yolcu et al. 2011), was applied to the soil (0-5 cm) in each plot when the seedbed was prepared each year. A standard phosphorus fertilizer application at a dosage of 75 kg P₂O₅ ha⁻¹ into the soil (0-5 cm) in each plot during the seedbed preparation in each year. The corn silage (Zea mays L.) variety OSSK-596, which is suitable for this region (Güney et al., 2010) was sown in the middle of May in 2012 and 2013 at a seeding rate of 40 kg ha⁻¹ (Kara, 2006). Weed control was done by hand-hoeing at 20-25 cm and
50 cm plant height twice each year, respectively. Irrigation was applied four times in July and August according to corn water requirements in each year.

**Plant and Soil Analyses**

Soils samples were collected a week prior to the establishment of the experiment in the first year of the research. Soil samples from the trial area were air-dried, crushed and passed through a 2-mm sieve prior to soil analysis. Soil samples were analyzed for Olsen-P (Olsen et al., 1954), pH (1:2.5 H₂O w/v) (McLean, 1982), organic matter (OM) (Nelson and Sommers, 1982), K (Rhoades, 1982) and Kjeldahl-N (Bremner, 1996).

Corn was harvested (at milk dough stage-dough seed stage) (Gucuk and Baytekin, 1999) in a 6.3 m² area of each plot in the first week of September in each year. Plant height, leaf, stem and corncob rate were calculated as a mean of five plants. Corn samples were dried at 60 °C for 48 h to calculate dry matter rate and yield in the oven. Corn samples were ground to pass through a 1-mm sieve prior to soil analysis. The Kjeldahl method and a Vapodest 10 Rapid Kjeldahl Distillation Unit (Gerhardt, Koenigswinter, Germany) were used to determine corn for silage total N (Bremner, 1996). ADF and NDF concentrations of silage corn were determined according to Van Soest (1963) with an ANKOM fiber analyzer unit (A220, serial number F2303341, USA).

**Statistical Analyses**

Data were subjected to the analysis of variance using the MSTAT-C procedure. Means were separated with LSD test to study the significance at 5% level of probability among different applications.

**Results**

**Silage and Dry Matter Yield**

The effect of year was significant for silage yield and dry matter yield (Table 3). The greatest silage yield was obtained NₓZ₁ (111867 kg ha⁻¹) and NₓZ₁ (111663 kg ha⁻¹) applications of silage corn in 2012, whereas N₁ and N₁ application gave 94120 kg ha⁻¹ and 93067 kg ha⁻¹ silage yield, respectively (Table 3). NₓZ₁ application produced the highest silage yield (81143 kg ha⁻¹), while N₁ application produced the highest silage yield amongst all nitrogen applications at 76667 kg ha⁻¹ in 2013 (Table 3). NₓZ₁ application produced the highest dry matter yield (35745 kg ha⁻¹) in 2012, whereas N₁ application had the highest dry matter yield amongst all nitrogen applications, producing 29434 kg ha⁻¹ dry matter yield. The highest dry matter yield occurred in NₓZ₁ (24885 kg ha⁻¹) and NₓZ₁ (24535 kg ha⁻¹) applications in 2013, while N₁ application produced the highest dry matter yield amongst all nitrogen applications at 23810 kg ha⁻¹ (Table 3).

| Treatments | SY (kg ha⁻¹)  | DMY (kg ha⁻¹) |
|------------|---------------|---------------|
|            | 2012          | 2013          | 2012          | 2013          |
| Control    | 49327 G       | 52403 E       | 14462 G       | 15278 E       |
| Z₁         | 55603 FG      | 59097 DE      | 17635 FG      | 17719 DE      |
| Z₂         | 58087 EFG     | 62506 B-E     | 16853 FG      | 18287 B-E     |
| Z₃         | 65496 D-G     | 59363 CDE     | 20452 EFG     | 17804 C-E     |
| N₁         | 79653 B-F     | 72593 A-D     | 24678 B-F     | 20786 A-E     |
| N₂         | 94120 ABC     | 72713 A-D     | 27991 A-E     | 21361 A-D     |
| N₃         | 93067 ABC     | 76667 A-D     | 29434 A-D     | 23810 ABC     |
| NₓZ₁       | 82050 B-E     | 68620 A-E     | 24073 C-F     | 20133 A-E     |
| NₓZ₂       | 77993 C-F     | 75440 A-D     | 22892 D-G     | 21862 A-D     |
| NₓZ₃       | 87131 A-D     | 76570 A-D     | 26944 A-E     | 22708 A-D     |
| NₓZ₁       | 88780 A-D     | 81143 A       | 27221 A-E     | 24885 A       |
| NₓZ₂       | 92470 ABC     | 76440 A-D     | 29593 A-D     | 22143 A-D     |
| NₓZ₃       | 111663 A      | 80110 AB      | 35745 A       | 24535 A       |
| NₓZ₁       | 94990 ABC     | 79093 AB      | 30393 A-D     | 24097 AB      |
| NₓZ₂       | 105980 AB     | 79273 AB      | 32502 ABC     | 23812 ABC     |
| NₓZ₃       | 111867 A      | 76826 ABC     | 33491 AB      | 23561 A-D     |
| Mean       | 84267 A       | 71804 B       | 25897 A       | 21424 B       |

**F-test**

| Application | **       | **       | **       |
|-------------|---------|---------|---------|
| Year        | **      | **      |         |
| Year x Application | **     |         | **      |

*Values followed by capital in a column shows significantly differences at P<0.01 level.
**Significant at 1% level, ns: non-significant.
Dry Matter Rate, Crude Protein and ADF

Year effect was not significant for dry matter rate, crude protein content and ADF (Table 4). The highest dry matter rate occurred in N₂ (31.3%) and N₂Z₃ (31.3%) applications based on means across 2012 and 2013 (Table 4). N₂Z₁ (11.7%), N₂Z₂ (11.6%), N₂Z₃ (11.5%), N₃ (11.4%) and N₂Z₂ (11.3%) applications produced greater crude protein contents than the others based on means across 2012 and 2013. There were no significant differences in terms of ADF among applications of zeolite, nitrogen and zeolite + nitrogen based on means across 2012 and 2013 (Table 4).

Table 4. Dry matter rate (DMR), crude protein content (CP) and acid detergent fiber (ADF) of silage corn in response to applications of zeolite, nitrogen and addition of zeolite to nitrogen based on means across 2012 and 2013

| Treatments | DMR (%) | CP (%) | ADF (%) |
|------------|---------|--------|---------|
| Control    | 29.3 ab | 7.8 D  | 30.6    |
| Z₁         | 29.2 b  | 8.9 CD | 30.6    |
| Z₂         | 29.2 b  | 9.0 CD | 29.4    |
| Z₃         | 30.7 ab | 9.3 C  | 28.8    |
| N₁         | 29.8 ab | 9.5 C  | 29.7    |
| N₂         | 29.5 ab | 11.1 AB| 30.5    |
| N₃         | 31.3 a  | 11.4 A | 30.7    |
| N₁Z₁       | 29.3 ab | 9.7 BC | 30.0    |
| N₁Z₂       | 29.2 b  | 9.8 BC | 29.3    |
| N₁Z₃       | 30.3 ab | 10.2 ABC| 29.7   |
| N₂Z₁       | 30.7 ab | 11.0 AB| 31.2    |
| N₂Z₂       | 30.5 ab | 11.3 A | 30.5    |
| N₂Z₃       | 31.3 a  | 10.9 AB| 30.0    |
| N₂Z₁       | 31.2 ab | 11.5 A | 30.3    |
| N₂Z₂       | 30.3 ab | 11.6 A | 30.4    |
| N₁Z₃       | 30.7 ab | 11.7 A | 30.7    |
| Mean       | 30.2    | 10.3   | 30.2    |

F-test

| Application |    | **| ns |
|-------------|----|---|----|
| Year        |   | ns|    |
| Year x Application | ns | ns| ns |

Values followed by small and capital in a column show significantly differences at P<0.05 level and P<0.01 level, respectively.

*: Significant at 5% level, **: Significant at 1% level, ns: non-significant.

NDF, Corncob Rate and Stem Rate

The effect of trial year was not significant for NDF, corncob rate and stem rate (Table 5). Low NDF is important in terms of quality. Z₁ (46.8%), Z₃ (53.5%), N₁ (53.7%), N₁Z₁ (53.8%), N₁Z₃ (53.9%) and control (54.2%) applications caused lower NDF contents than the others based on means across 2012 and 2013 (Table 5). The greatest corncob rates were found in N₁Z₃ (42.1%) and N₁Z₃ (41.5%) applications based on means across 2012 and 2013, while N₁ application had the highest corncob rate amongst all nitrogen applications, producing a 39.5% corncob rate (Table 5). There were no differences in terms of stem rate between applications of zeolite, nitrogen and zeolite + nitrogen based on means across 2012 and 2013 (Table 5).

Plant Height and Leaf Rate

The greatest plant height was obtained in N₁Z₃ (286.3 cm) applications for silage corn in 2012 (Table 6). N₂ application produced the highest plant height amongst all nitrogen applications at 246.7 cm in 2012. N₁Z₁ (231.0 cm), N₁Z₃ (229.0 cm) and N₁Z₃ (227.3 cm) applications had higher plant heights than the others in 2013 (Table 6), whereas N₂ application produced the highest plant height amongst all nitrogen applications at 224.3 cm. N₁Z₁ (14.1%) and N₁Z₂ (14.1%) applications caused greater leaf rate than others in 2012, whereas N₂ application produced the highest plant height amongst all nitrogen applications and had a 12.1% leaf rate (Table 6).
Table 5. Neutral detergent fiber (NDF), corncob rate and stem rate of silage corn in response to applications of zeolite, nitrogen and addition of zeolite to nitrogen based on means across 2012 and 2013

| Treatments | NDF (%) | Corncob rate (%) | Stem rate (%) |
|------------|---------|------------------|---------------|
| Control    | 54.2 ab | 36.0 b           | 53.6          |
| Z1         | 46.8 b  | 37.3 ab          | 53.8          |
| Z2         | 56.0 a  | 37.2 ab          | 53.0          |
| Z3         | 53.5 ab | 36.0 b           | 52.6          |
| N1         | 53.7 ab | 37.2 ab          | 51.5          |
| N2         | 54.9 a  | 39.0 ab          | 49.3          |
| N3         | 57.4 a  | 39.5 ab          | 48.4          |
| N1Z1       | 53.8 ab | 39.6 ab          | 49.4          |
| N1Z2       | 55.2 a  | 39.7 ab          | 49.3          |
| N1Z3       | 53.9 ab | 42.1 a           | 47.1          |
| N2Z1       | 55.7 a  | 38.2 ab          | 49.1          |
| N2Z2       | 57.1 a  | 39.0 ab          | 48.2          |
| N2Z3       | 56.2 a  | 40.5 ab          | 46.8          |
| N3Z1       | 58.0 a  | 38.1 ab          | 48.8          |
| N3Z2       | 58.5 a  | 38.4 ab          | 49.1          |
| N3Z3       | 58.4 a  | 41.5 a           | 47.3          |
| Mean       | 55.2    | 38.7             | 49.8          |

F-test

| Application |  |  | ns |
|-------------|  |  |    |
| Year        | ns | ns | ns |
| Year x Application | ns | ns | ns |

Values followed by small in a column shows significantly differences at P<0.05 level.

*: Significant at 5% level, ns: non-significant.

Table 6. Plant height and leaf rate of silage corn in response to applications of zeolite, nitrogen and addition of zeolite to nitrogen

| Treatments | Plant Height (cm) | Leaf Rate (%) |
|------------|------------------|---------------|
|            | 2012             | 2013          | 2012 | 2013 |
| Control    | 204.0 E          | 205.0 D       | 11.2 bcd | 9.6 |
| Z1         | 229.3 B-E        | 212.0 BCD     | 10.4 d | 7.6 |
| Z2         | 234.3 B-E        | 205.3 D       | 10.6 d | 9.0 |
| Z3         | 218.3 DE         | 206.7 CD      | 13.2 abc | 6.6 |
| N1         | 222.6CDE         | 217.6 A-D     | 11.2 cd | 11.6 |
| N2         | 246.7 A-E        | 216.7 A-D     | 12.0 a-d | 10.1 |
| N3         | 229.3 B-E        | 224.3 AB      | 11.7 bcd | 10.3 |
| N1Z1       | 236.3 B-E        | 216.3 A-D     | 12.3 a-d | 9.3 |
| N1Z2       | 251.0 A-E        | 217.0 A-D     | 13.0 abc | 10.9 |
| N1Z3       | 258.6 A-D        | 226.7 AB      | 13.2 abc | 12.2 |
| N2Z1       | 261.3 A-D        | 220.3 ABC     | 14.1 a  | 11.6 |
| N2Z2       | 273.3ABC         | 221.3 ABC     | 13.4 ab | 11.8 |
| N2Z3       | 257.3 A-D        | 223.3 AB      | 11.1 cd | 13.1 |
| N3Z1       | 271.7ABC         | 231.0 A       | 12.1 a-d | 14.2 |
| N3Z2       | 274.0 AB         | 227.3 A       | 14.1 a  | 10.8 |
| N3Z3       | 286.3 A          | 229.0 A       | 10.1 d  | 12.3 |
| Mean       | 247.1            | 218.7         | 12.1    | 10.7 |

F-test (LSD)

| Application |  |  | ns |
|-------------|  |  |    |
| Year        | ** | * |    |
| Year x Application | ns | ns | |

Values followed by small and capital in a column shows significantly differences at P<0.05 level and P<0.01 level, respectively.

*: Significant at 5% level, **: Significant at 1% level, ns: non-significant.
Discussion

The applications of N$_2$Z$_1$ and of N$_2$Z$_2$ applications in 2012 and N$_2$Z$_1$ application in 2013 produced greater silage yield amongst all applications. Similarly, Aghaaliikhani et al., (2012) determined that the application of zeolite + nitrogen application increased the seed yield of canola. Furthermore, Gjoka et al., (2011) reported that the application of zeolite + NPK application increased the crop yield of ryegrass. In addition, other researchers found that the application of zeolite + nitrogen application increased the seed yield of rice (Sepaskhah and Barzegar, 2010) and cowpea (Azarpour et al., 2011).

N$_2$Z$_2$ application in 2012 and N$_2$Z$_1$ application in 2013 gave greatest dry matter yield amongst all applications. Similarly, Bernardi et al. (2011) reported that the application of zeolite + nitrogen application increased corn dry matter production.

The greatest dry matter rate was found in N$_2$Z$_2$ and N$_3$ application. The application of N$_2$Z$_1$ application produced equal dry matter rate to the N$_3$ application based on means across 2012 and 2013. The application of N$_2$Z$_2$ and N$_1$ application had the highest crude protein content amongst all applications based on means across 2012 and 2013. Zeolite + nitrogen applications increased efficiency of nitrogen and decreased the nitrogen requirement in terms of dry matter rate and crude protein content. Similarly, Sepaskhah and Barzegar (2010) found that the application of zeolite + nitrogen application increased rice grain protein contents. Moreover, Bernardi et al. (2011) found that the application of zeolite + nitrogen increased corn N concentrations that are related to crude protein content. Furthermore, Ahmed et al. (2010) reported that zeolite + inorganic fertilizers remarkably increased N uptake and its use efficiency for corn.

Low ADF and NDF values are desirable in terms of forage quality (Yolcu et al., 2016). Zeolite + nitrogen application had no effect on ADF content of silage corn based on means across 2012 and 2013. Similarly, Bernardi et al. (2011) determined that the application of zeolite + nitrogen had no effect on ADF concentrations of corn. N$_2$Z$_2$ and N$_3$Z$_2$ application gave the highest corn cob rate among all applications. N$_2$Z$_1$ application in 2012 and N$_1$Z$_1$, N$_2$Z$_1$ and N$_3$Z$_1$ in 2013 produced the highest plant height amongst all applications. Similarly, Azarpour et al. (2011) found that application of zeolite + nitrogen increased plant height in cowpea. The N$_2$Z$_1$ and N$_1$Z$_2$ application had the highest leaf rate amongst all applications in 2012.

Conclusion

The addition of zeolite to nitrogen application enhanced silage yield by 5.8-18.9%, dry matter yield by 4.5-21.4%, corn cob rate by 6.6%, plant height by 3.0-16.1% and leaf rate by 17.5%. Further, the addition of zeolite to medium or low nitrogen application produced similar silage yield, dry matter yield, dry matter rate, crude protein content, ADF, NDF, corn cob rate, stem rate, plant height and leaf rate in comparison to the highest-level nitrogen application.

All these results show that in plants requiring high doses of nitrogen and in environments where nitrogen leakage is a problem, zeolite can be used to increase the efficiency of nitrogen and reduce the need for nitrogen by absorbing nitrogen and preventing nitrate leakage.

Future studies in this topic should be determining of long-term effects of zeolite in the soil and cost efficiency of zeolite.

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