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RESEARCH ARTICLE

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

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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 (Z_1: 500, Z_2: 1000, Z_3: 1500 kg ha^{-1}), three nitrogen (N_1: 50, N_2: 100, N_3: 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.

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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; Gholamhoseini 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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Zeolite 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 SiO_4 and AlO_4 tetrahedral, which are linked by sharing all oxygen atoms, then the partial substitution of Si^{4+} by Al^{3+} 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 NH_4^+ (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, corncob 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	Mean Temperature (°C)			Precipitation (mm)		
	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
Z_1	500 kg ha^{-1} zeolite
Z_2	1000 kg ha^{-1} zeolite
Z_3	1500 kg ha^{-1} zeolite
N_1	50 kg ha^{-1} nitrogen
N_2	100 kg ha^{-1} nitrogen
N_3	150 kg ha^{-1} nitrogen
N_1Z_1	50 kg ha^{-1}nitrogen + 500 kg ha^{-1}zeolite
N_1Z_2	50 kg ha^{-1}nitrogen + 1000 kg ha^{-1}zeolite
N_1Z_3	50 kg ha^{-1}nitrogen + 1500 kg ha^{-1}zeolite
N_2Z_1	100 kg ha^{-1}nitrogen + 500 kg ha^{-1}zeolite
N_2Z_2	100 kg ha^{-1}nitrogen + 1000 kg ha^{-1}zeolite
N_2Z_3	100 kg ha^{-1}nitrogen + 1500 kg ha^{-1}zeolite
N_3Z_1	150 kg ha^{-1}nitrogen + 500 kg ha^{-1}zeolite
N_3Z_2	150 kg ha^{-1}nitrogen + 1000 kg ha^{-1}zeolite
N_3Z_3	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} P_2O_5), lime (4.1% $CaCO_3$) 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), corncob 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 height reached 40-50 cm in each plot in each year. Ammonium sulfate [$(NH_4)_2$ SO4] 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 P_2O_5 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 (Guney 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 H_2O 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 m^2 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 for analyses. 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 N_3Z_3 (111867 kg ha^{-1}) and N_2Z_3 (111663 kg ha^{-1}) applications of silage corn in 2012, whereas N_2 and N_3 application gave 94120 kg ha^{-1} and 93067 kg ha^{-1} silage yield, respectively (Table 3). N_2Z_1 application produced the highest silage yield (81143 kg ha^{-1}), while N_3 application produced the highest silage yield amongst all nitrogen applications at 76667 kg ha^{-1} in 2013 (Table 3). N_2Z_3 application produced the highest dry matter yield (35745 kg ha^{-1}) in 2012, whereas N_3 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 N_2Z_1 (24885 kg ha^{-1}) and N_2Z_3 (24535 kg ha^{-1}) applications in 2013, while N_3 application produced the highest dry matter yield amongst all nitrogen applications at 23810 kg ha^{-1} (Table 3).

Table 3. Silage yield (SY) and dry matter yield (DMY) of silage corn in response to applications of zeolite, nitrogen and addition of zeolite to nitrogen[1]

Treatments	SY (kg ha^{-1})		DMY (kg ha^{-1})	
	2012	2013	2012	2013
Control	49327 G	52403 E	14462 G	15278 E
Z_1	55603 FG	59097 DE	17635 FG	17719 DE
Z_2	58087 EFG	62506 B-E	16853 FG	18287 B-E
Z_3	65496 D-G	59363 CDE	20452 EFG	17804 C-E
N_1	79653 B-F	72593 A-D	24678 B-F	20786 A-E
N_2	94120 ABC	72713 A-D	27991 A-E	21361 A-D
N_3	93067 ABC	76667 A-D	29434 A-D	23810 ABC
N_1Z_1	82050 B-E	68620 A-E	24073 C-F	20133 A-E
N_1Z_2	77993 C-F	75440 A-D	22892 D-G	21862 A-D
N_1Z_3	87131 A-D	76570 A-D	26944 A-E	22708 A-D
N_2Z_1	88780 A-D	81143 A	27221 A-E	24885 A
N_2Z_2	92470 ABC	76440 A-D	29593 A-D	22143 A-D
N_2Z_3	111663 A	80110 AB	35745 A	24535 A
N_3Z_1	94990 ABC	79093 AB	30393 A-D	24097 AB
N_3Z_2	105980 AB	79273 AB	32502 ABC	23812 ABC
N_3Z_3	111867 A	76826 ABC	33491 AB	23561 A-D
Mean	84267A	71804 B	25897 A	21424 B
F-test				
Application	**	**	**	**
Year	**		**	
Year x Application	**		**	

[1]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 N_3 (31.3%) and N_2Z_3 (31.3%) applications based on means across 2012 and 2013 (Table 4). N_3Z_3 (11.7%), N_3Z_2 (11.6%), N_3Z_1 (11.5%), N_3 (11.4%) and N_2Z_2 (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[1]

Treatments	DMR (%)	CP (%)	ADF (%)
Control	29.3 ab	7.8 D	30.6
Z_1	29.2 b	8.9 CD	30.6
Z_2	29.2 b	9.0 CD	29.4
Z_3	30.7 ab	9.3 C	28.8
N_1	29.8 ab	9.5 C	29.7
N_2	29.5 ab	11.1 AB	30.5
N_3	31.3 a	11.4 A	30.7
N_1Z_1	29.3 ab	9.7 BC	30.0
N_1Z_2	29.2 b	9.8 BC	29.3
N_1Z_3	30.3 ab	10.2 ABC	29.7
N_2Z_1	30.7 ab	11.0 AB	31.2
N_2Z_2	30.5 ab	11.3 A	30.5
N_2Z_3	31.3 a	10.9 AB	30.0
N_3Z_1	31.2 ab	11.5 A	30.3
N_3Z_2	30.3 ab	11.6 A	30.4
N_3Z_3	30.7 ab	11.7 A	30.7
Mean	30.2	10.3	30.2
F-test			
Application	*	**	ns
Year	ns	ns	ns
Year x Application	ns	ns	ns

[1]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.

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. Z_1 (46.8%), Z_3 (53.5%), N_1 (53.7%), N_1Z_1 (53.8%), N_1Z_3 (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 N_1Z_3 (42.1%) and N_3Z_3 (41.5%) applications based on means across 2012 and 2013, while N_3 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 N_3Z_3 (286.3 cm) applications for silage corn in 2012 (Table 6). N_2 application produced the highest plant height amongst all nitrogen applications at 246.7 cm in 2012. N_3Z_1 (231.0 cm), N_3Z_3 (229.0 cm) and N_3Z_2 (227.3 cm) applications had higher plant heights than the others in 2013 (Table 6), whereas N_3 application produced the highest plant height amongst all nitrogen applications at 224.3 cm. N_2Z_1 (14.1%) and N_3Z_2 (14.1%) applications caused greater leaf rate than others in 2012, whereas N_2 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[1]

Treatments	NDF (%)	Corncob rate (%)	Stem rate (%)
Control	54.2 ab	36.0 b	53.6
Z_1	46.8 b	37.3 ab	53.8
Z_2	56.0 a	37.2 ab	53.0
Z_3	53.5 ab	36.0 b	52.6
N_1	53.7 ab	37.2 ab	51.5
N_2	54.9 a	39.0 ab	49.3
N_3	57.4 a	39.5 ab	48.4
N_1Z_1	53.8 ab	39.6 ab	49.4
N_1Z_2	55.2 a	39.7 ab	49.3
N_1Z_3	53.9 ab	42.1 a	47.1
N_2Z_1	55.7 a	38.2 ab	49.1
N_2Z_2	57.1 a	39.0 ab	48.2
N_2Z_3	56.2 a	40.5 ab	46.8
N_3Z_1	58.0 a	38.1 ab	48.8
N_3Z_2	58.5 a	38.4 ab	49.1
N_3Z_3	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

[1]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[1]

Treatments	Plant Height (cm)		Leaf Rate (%)	
	2012	2013	2012	2013
Control	204.0 E	205.0 D	11.2 bcd	9.6
Z_1	229.3 B-E	212.0 BCD	10.4 d	7.6
Z_2	234.3 B-E	205.3 D	10.6 d	9.0
Z_3	218.3 DE	206.7 CD	13.2 abc	6.6
N_1	222.6CDE	217.6 A-D	11.2 cd	11.6
N_2	246.7 A-E	216.7 A-D	12.0 a-d	10.1
N_3	229.3 B-E	224.3 AB	11.7 bcd	10.3
N_1Z_1	236.3 B-E	216.3 A-D	12.3 a-d	9.3
N_1Z_2	251.0 A-E	217.0 A-D	13.0 abc	10.9
N_1Z_3	258.6 A-D	226.7 AB	13.2 abc	12.2
N_2Z_1	261.3 A-D	220.3 ABC	14.1 a	11.6
N_2Z_2	273.3ABC	221.3 ABC	13.4 ab	11.8
N_2Z_3	257.3 A-D	223.3 AB	11.1 cd	13.1
N_3Z_1	271.7ABC	231.0 A	12.1 a-d	14.2
N_3Z_2	274.0 AB	227.3 A	14.1 a	10.8
N_3Z_3	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	

[1]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_2Z_3 and of N_3Z_3 applications in 2012 and N_2Z_1 application in 2013 produced greater silage yield amongst all applications. Similarly, Aghaalikhani 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_2Z_3 application in 2012 and N_2Z_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_2Z_3 and N_3 application. The application of N_2Z_3 application produced equal dry matter rate to the N_3 application based on means across 2012 and 2013. The application of N_2Z_2 and N_3 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_1Z_3 and N_3Z_3 application gave the highest corncob rate among all applications. N_3Z_3 application in 2012 and N_3Z_1, N_3Z_3 and N_3Z_2 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_2Z_1 and N_3Z_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%, corncob 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, corncob 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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