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Influence of Zeolite on Nitrogen Fractions, Nitrogen Use Efficiency and Nitrogen Uptake of Maize

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Authors' contributions

This work was carried out in collaboration among all authors. Author CR designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors KJR and TA managed the analyses of the study. Author KS managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Imbalanced use of fertilizers for agricultural production has now become a global concern. As a result, studies on how to use efficient methods to reduce nutrient applications at the same time increasing or maintaining crop yield, reducing nutrient losses and improving nutrient use efficiency are imperative. Accordingly, a pot study was conducted to evaluate whether zeolite application might improve selected soil properties, nitrogen use efficiency during maize cultivation. Among all treatments, irrespective of the nitrogen level, NUE (N recovery and agronomic use efficiency of N) showed an increasing trend with the increase of zeolite levels, nitrogen levels and their combination. The highest N recovery and agronomic NUE was obtained in $N_{200}Z_{7.5}$ (Nitrogen @ 200 kg ha^{-1} + Zeolite @ 7.5 t ha^{-1}), was on par with $N_{200}Z_5$ (Nitrogen @ 200 kg ha^{-1} + Zeolite @ 5 t ha^{-1}). N uptake by maize at harvest was highest in $N_{200}Z_{7.5}$ (Nitrogen @ 200 kg ha^{-1} + Zeolite @ 7.5 t ha^{-1}).

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Keywords: Ammoniacal nitrogen; nitrate nitrogen; NUE; niitrogen uptake.

1. INTRODUCTION

Maize (*Zea mays* L.) is the third most important cereal crop in India after rice and wheat [1]. Maize is used as human food and animal feed at the same time. It is also widely used for corn starch industry, corn oil production, baby corns *etc*. Maize is grown throughout the year in India. It is predominantly a *kharif* crop with 85% of the area under cultivation in the season. The increasing use of maize as feed, increasing interest of the consumers in nutritionally enriched products and rising demand for maize seed are the core driving forces behind emerging importance of maize crop in India.

Application of Nitrogen fertilizers in recent times has greatly increased the costs of food production and has also led to increased accumulation of N, which can result in eutrophication of lakes and waterways [2]. As a result, studies on how to use efficient methods to reduce nutrient applications for increasing or maintaining crop yield, reducing nutrient losses and improving nutrient use efficiency are imperative [3]. For instance, sustainable nutrient use efficiency could be attained by agronomic practices which take into account timely synchronization of nutrient application with plant roots development, or use of slow-release fertilizers, and foliar feeding [4].

In this regard, inclusion of zeolites in fertilizers management for agriculture is essential as besides serving as soil conditioner (including soil fertility improvement), zeolites have the potential to increase crop yield [5]. Zeolites are crystalline, hydrated aluminosilicates that have a three-dimensional crystal structure and are characterized by an abundant pore structure and high surface area (400–850 $m^2 g^{-1}$) [6]. They also have an ability to lose and gain water reversibly, and to exchange constituent elements without a major change in structure [7]. Ahmed et al. [8] reported that Zeolite amendment of an acid sulfate soil reduced NH_3 loss and increased NUE. Treatments with CZ improved N uptake and use efficiency in the maize crop tested [9]. Accordingly, the aim of this study is to evaluate whether the soil, when amended with zeolite might improve selected soil properties, uptake and use efficiency of nutrients by maize crop.

2. MATERIALS AND METHODS

A pot study was conducted at Professor Jayashankar Telangana State Agricultural University, College of Agriculture, Rajendranagar, which is located in RangaReddy district of Telangana state during *kharif*, 2018-19. The soil used in the study was a loamy sand. Soil samples were taken at 0-15 cm depth using an auger, air dried and ground to pass a 5 mm sieve. The treatments details and properties of zeolite used in the study are mentioned in Table 1 and Table2.

The test crop used in this experiment was maize (DHM 117). 3 levels of nitrogen (100, 150, 200 kg N ha^{-1} *i.e.,* 357.14, 535.71, 714.28 mg pot^{-1}respectively) and 4 levels of zeolite (0, 2.5, 5, 7.5 t ha^{-1} *i.e.,* 0, 8.93, 17.26, 26.79 g pot^{-1} respectively) were applied in different treatments. Phosphorous (P_2O_5) and Potassium (K_2O) were applied @ 60-60 kg ha^{-1} (24.29 - 24.29 mg pot^{-1}) uniformly to all the treatments including control. The experimental design was Factorial Completely Randomized Design FCRD (Factor 1: Zeolite; Factor 2: Nitrogen) and the treatments were replicated three times.

The exchangeable NH_4+ and available NO_3- were extracted from the soil by extracting with 2M KCl, followed by steam distillation with 2.5 % NaOH in presence of 0.2 g MgO (NH_4^+-N) or of 0.2 g Devarada's alloy (NO_3^--N) as described by Bremner [10].

Maize plants from the pots were removed at 30, 60, 90 days after sowing. The plants were removed along with the roots and the adhered soil particles to maize plant samples were removed and the plant samples were shade dried and kept in the hot air oven at 60ºC - 80ºC until constant weight is attained. The dried plant samples were then powdered and this powder was used for further analysis. The dry matter obtained from each treatment and their respective nutrient contents were used to compute nutrient uptake at 30, 60, 90 days after sowing and at harvest. Nitrogen uptake, Nitrogen recovery and Agronomic efficiency of nitrogen equations are mentioned below.

Table 1. Treatment details

Particulars	Abbreviated as
No Nitrogen and No Zeolite	N_0Z_0
Nitrogen @100 kg ha^{-1} + No Zeolite	$N_{100}Z_0$
Nitrogen @100 kg ha^{-1} + Zeolite @ 2.5 t ha^{-1}	$N_{100}Z_{2.5}$
Nitrogen @100 kg ha^{-1} + Zeolite @ 5 t ha^{-1}	$N_{100}Z_5$
Nitrogen @100 kg ha^{-1} + Zeolite @ 7.5 t ha^{-1}	$N_{100}Z_{7.5}$
Nitrogen @150 kg ha^{-1} + No Zeolite	N_{150} Z_0
Nitrogen @150 kg ha^{-1} + Zeolite @ 2.5 t ha^{-1}	N_{150} $Z_{2.5}$
Nitrogen @150 kg ha^{-1} + Zeolite @ 5 t ha^{-1}	N_{150} Z_5
Nitrogen @150 kg ha^{-1} + Zeolite @ 7.5 t ha^{-1}	N_{150} $Z_{7.5}$
Nitrogen @ 200 kg ha^{-1}+ No Zeolite	N_{200} Z_0
Nitrogen @200 kg ha^{-1} + Zeolite @ 2.5 t ha^{-1}	N_{200} $Z_{2.5}$
Nitrogen @200 kg ha^{-1} + Zeolite @ 5 t ha^{-1}	N_{200} Z_5
Nitrogen @200 kg ha^{-1} + Zeolite @ 7.5 t ha^{-1}	N_{200} $Z_{7.5}$

Table 2. Properties of zeolite used in the study

S. no.	Property	Values
1.	Moisture at 105°C	0-10%
2.	Water Absorption	90-100%
3.	Bulk Density (Mg m^{-3})	0.35-0.45
4.	Ph	8.0 - 9.0
5.	EC (dS m^{-1})	5.5
6.	CEC (cmol(p+)kg^{-1})	130-135
7.	Silica (SiO_2)	78-82%
8.	Alumina (Al_2O_3)	6-8%

2.1 Nitrogen Uptake (Equation:1)

N Uptake (mg pot^{-1}) = N content (%) x Dry matter (g pot-1)/ 100

Nitrogen use efficiency is indicated by the amount of N uptake by plant to applied N. Nitrogen use efficiency was calculated by different parameters which are given below.

2.2 Nitrogen Recovery (Equation:2)

N recovery (%) = TUN-CUN x 100/ AF

2.3 Agronomic Efficiency of Nitrogen (Equation:3)

Agronomic efficiency of N (g grain g N applied^{-1}) = GYF-GYC/ AF

Where,

TUN - Total uptake of nitrogen from respective fertilized pot.
CUN - Uptake of nitrogen from control pot.
GYF - Grain yield from respective fertilized pot.
GYC - Grain yield from control pot.
AF - Applied N fertilizer (urea).

The data recorded from the pot study was statistically computed by adopting factorial completely randomized design using standard procedures [11]. The critical difference was used to evaluate the effects of treatments.

3. RESULTS AND DISCUSSION

3.1 N Uptake

The zeolite level, $Z_{7.5}$ showed highest N uptake (mean value - 307.41) by grains at harvest (Fig. 1), followed by Z_5 (mean value - 288.96), $Z_{2.5}$ (mean value - 254.34) and Z_0 (mean value - 219.24). The nitrogen level, N_{200} produced significantly higher N uptake (mean value - 376.43), followed by N_{150} (mean value - 265.14) and N_{100} (mean value - 160.89). The interaction effect of zeolite and nitrogen also showed significant increase in N uptake. The highest N uptake in grain (425.83) was observed in

$N_{200}Z_{7.5}$, which was significantly superior over all other treatments. In $N_{200}Z_5$ the N uptake was 408.21 while the lowest N uptake in grain was observed in 67.42. In stover, the zeolite level, $Z_{7.5}$ produced significantly higher N uptake (mean value - 181.37) compared to Z_0 (mean value - 115.36), $Z_{2.5}$ (mean value - 135.57) Z_5 (mean value - 159.79) and control (26.91). The nitrogen also showed significant effect on N uptake in maize straw (Table 2. and Fig. 1.). The nitrogen level, N_{200} produced significantly higher N uptake (mean value - 242.58), followed by N_{150} (mean value - 138.54) and N_{100} (mean value - 60.70). The interaction effect of zeolite and nitrogen also showed significant increase in N uptake. The highest N uptake was observed in $N_{200}Z_{7.5}$ (278.45) followed by $N_{200}Z_5$ (265.05) and the least N uptake was found in control (26.91).

The positive effect of zeolite on soil CEC that in turn increases NH_4^+ adsorption and reduction of leaching losses which resulted in increased N availability in the plant root zone might be the responsible factor for enhanced nitrogen uptake. The similar results were obtained by Lija *et al*. [12], who reported that combination of zeolite with compound fertilizer enhanced N uptake in maize and application of higher doses of zeolite along with nitrogen enhanced N uptake in rice grain and straw (Kavoosi, 2007). Ahmed et al. [13] found that zeolite had significantly improved N uptake in maize.

The data regarding ammoniacal nitrogen at 30, 60, 90 DAS was presented in Table 3. Zeolite has significant influence on the ammoniacal nitrogen in soil. At 30 DAS, $Z_{7.5}$ have recorded significantly higher ammoniacal nitrogen (mean value - 15.41), followed by Z_5 (mean value - 14.51) and lowest ammoniacal nitrogen among four zeolite levels was observed in Z_0 (mean value - 13.53). Nitrogen also has shown significant effect on ammoniacal nitrogen at 30 DAS. Nitrogen level, N_{200} recorded significantly higher ammoniacal nitrogen (mean value - 14.83) and the lowest ammoniacal nitrogen among three nitrogen levels was observed in N_{100} (mean value - 14.09). The interaction between nitrogen and zeolite with respect to ammoniacal nitrogen at 30 DAS was non significant.

At 60 DAS, ammoniacal nitrogen was significantly higher in Z_0 (mean value - 30.69) while the lowest ammoniacal nitrogen among the four zeolite levels was observed in $Z_{7.5}$ (mean value - 17.75). Among nitrogen levels, the highest ammoniacal nitrogen was observed in N_{200} (mean value - 25.27) which was significantly superior over N_{150} (mean value - 23.72) and N_{100} (mean value - 19.54). There was significant interaction between nitrogen and zeolite. Among various combinations, $N_{200}Z_0$ recorded significantly higher ammoniacal nitrogen (36.20) followed by $N_{150}Z_0$ (32.41) while the lowest ammoniacal nitrogen was observed in control (21.37).

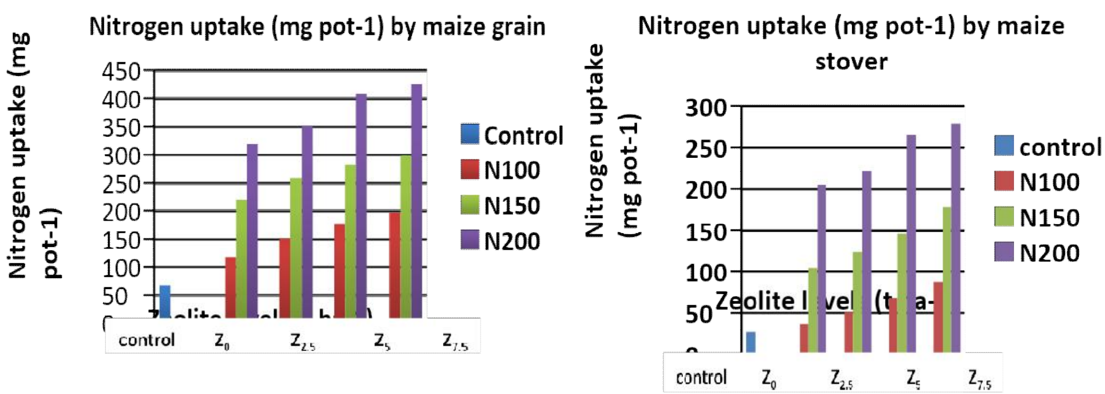

Fig. 1. Effect of different levels of nitrogen and zeolite on nitrogen uptake at harvest effect of different levels of nitrogen and zeolite on inorganic nitrogen fractions ammoniacal nitrogen (mg kg^{-1})

At 90 DAS, the ammoniacal nitrogen significantly increased from 15.78 (mean value) in Z_0 to 25.45 (mean value) in $Z_{7.5}$. Among three nitrogen levels, N_{200} recorded significantly higher ammoniacal nitrogen (mean value - 25.14) than rest of the nitrogen levels, N_{150} (mean value - 23.28) and N_{100} (mean value - 16.29). There was significant interaction observed between zeolite and nitrogen with respect to ammoniacal nitrogen at 90 DAS. The highest ammoniacal nitrogen was observed in $N_{200}Z_{7.5}$ (29.53), followed by $N_{150}Z_{7.5}$ (28.17). The lowest ammoniacal nitrogen was recorded in control (13.31).

At harvest, higher ammoniacal nitrogen (Table 4) was recorded in $Z_{7.5}$ (mean value - 17.27), followed by Z_5 (mean value - 16.62) which was on par with $Z_{2.5}$ (mean value - 16.09) and the lowest ammoniacal nitrogen among the four zeolite levels was observed in Z_0 (mean value - 15.40). Among nitrogen levels, N_{200} (mean value - 18.11) recorded highest ammoniacal nitrogen followed by N_{150} (mean value - 17.10). There was significant interaction observed between nitrogen and zeolite levels. Among all the treatments, ammoniacal nitrogen was higher in $N_{200}Z_{7.5}$ (19.14) was on par with $N_{150}Z_{7.5}$ (18.53) and $N_{200}Z_5$ (18.30). The lowest ammoniacal nitrogen was recorded in control (11.44).

A short time after zeolite application (upto 30 DAS), the ammoniacal nitrogen content was reduced due to NH_4^+ fixation by zeolite, but later on opposite was true. The increase was probably due to release of nitrogen from the zeolite crystal lattice. Similar results were obtained by Torma et al. [14] who found that initially, the treatments with zeolite showed 14 % - 20 % lower ammoniacal nitrogen than control. But at the end of the field experiment, treatments with zeolite showed 24 % - 59 % higher ammoniacal nitrogen than control. Increasing zeolite application rate irrespective of method of application had increased NH_4^+- N [15].

3.2 Nitrate Nitrogen (mg kg^{-1})

The data regarding nitrate nitrogen at 30 DAS was presented in Table 5. Zeolite has significant influence on the nitrate nitrogen in soil. At 30 DAS, $Z_{7.5}$ have recorded significantly higher nitrate nitrogen (mean value - 4.29), followed by Z_5 (mean value - 4.07) and lowest nitrate nitrogen among four zeolite levels was observed in Z_0 (mean value - 3.84). Nitrogen has also shown significant effect on nitrate nitrogen at 30 DAS. Nitrogen level, N_{200} recorded significantly higher nitrate nitrogen (mean value - 4.14) and the lowest nitrate nitrogen among three nitrogen levels was observed in N_{100} (mean value - 3.96). The interaction between nitrogen and zeolite with respect to nitrate nitrogen at 30 DAS was non significant.

At 60 DAS, nitrate nitrogen (Table 5. and Fig.2) was significantly higher in Z_0 (mean value - 9.97) while the lowest nitrate nitrogen among the four zeolite levels was observed in $Z_{7.5}$ (mean value - 6.74). Among nitrogen levels, the highest nitrate nitrogen was observed in N_{200} (mean value - 8.62) which was significantly superior over N_{150} (mean value - 8.23) and N_{100} (mean value - 7.19). There was significant interaction between nitrogen and zeolite. Among various combinations, $N_{200}Z_0$ recorded significantly higher nitrate nitrogen (11.35) followed by $N_{150}Z_0$ (10.40) while the lowest nitrate nitrogen was observed in $N_{100}Z_{7.5}$ (6.63).

At 90 DAS, the nitrate nitrogen (Table 5. and Fig.2) significantly increased from 6.74 (mean value) in Z_0 to 9.16 (mean value) in $Z_{7.5}$. The zeolite level, Z_5 (mean value - 8.65) was on par to $Z_{7.5}$. Among three nitrogen levels, N_{200} recorded higher nitrate nitrogen (mean value - 9.09) which was on par with N_{150} (mean value - 8.62). There was significant interaction observed between zeolite and nitrogen with respect to nitrate nitrogen at 90 DAS. Among various combinations, $N_{200}Z_{7.5}$ recorded higher nitrate nitrogen (10.18) which was on par with $N_{150}Z_{7.5}$ (9.84), $N_{200}Z_5$ (9.63), $N_{150}Z_5$ (9.21) $N_{200}Z_{2.5}$ (9.15).

At harvest, higher nitrate nitrogen (Table 6) was recorded in $Z_{7.5}$ (mean value -4.73), which followed by Z_5 (mean value - 4.57), whicb was on par with $Z_{2.5}$ (mean value -4.44) and the lowest nitrate nitrogen among the four zeolite levels was observed in Z_0 (mean value - 4.27). Among nitrogen levels, N_{200} (mean value - 14.65) recorded highest nitrate nitrogen which followed by N_{150} (mean value - 4.94) and lowest nitrate nitrogen was observed in N_{100} (mean value - 3.87). There was significant interaction observed between nitrogen and zeolite levels. Among all the treatments, nitrate nitrogen was higher in $N_{200}Z_{7.5}$ (5.20) which was on par with $N_{200}Z_5$ (5.05). The lowest nitrate nitrogen was recorded in control (2.86).

Table 3. Effect of different levels of nitrogen (kg ha^{-1}) and zeolite (t ha^{-1}) application on ammoniacal nitrogen (mg kg^{-1}) fraction at 30, 60 and 90 DAS

Levels	30 DAS					60 DAS					90 DAS				
	Z_0	$Z_{2.5}$	Z_5	$Z_{7.5}$	Mean (N)	Z_0	$Z_{2.5}$	Z_5	$Z_{7.5}$	Mean (N)	Z_0	$Z_{2.5}$	Z_5	$Z_{7.5}$	Mean (N)
N_{100}	13.50	13.97	14.29	14.61	14.09	23.46	18.82	18.56	17.34	19.54	13.58	15.73	17.17	18.67	16.29
N_{150}	13.58	14.09	14.48	15.32	14.37	32.41	24.15	20.90	17.43	23.72	15.43	23.86	25.66	28.17	23.28
N_{200}	13.82	14.42	14.77	16.31	14.83	36.20	24.86	21.53	18.49	25.27	18.33	25.40	27.32	29.53	25.14
Mean (Z)	13.63	14.16	14.51	15.41		30.69	22.61	20.33	17.75		15.78	21.66	23.38	25.45	
*Control (No nitrogen, no zeolite) – 12.06 mg kg^{-1}						*Control (No nitrogen, no zeolite) – 21.37 mg kg^{-1}					*Control (No nitrogen, no zeolite) – 13.31 mg kg^{-1}				

	S.Em. (±)				CD (p=0.05)		
	30 DAS	60 DAS	90 DAS		30 DAS	60 DAS	90 DAS
N	0.14	0.24	0.08	N	0.41	0.71	0.23
Z	0.16	0.28	0.09	Z	0.47	0.82	0.27
N X Z	0.28	0.48	0.16	N X Z	NS	1.42	0.47

Table 4. Effect of different levels of nitrogen (kg ha^{-1}) and zeolite (t ha^{-1}) application on ammoniacal nitrogen (mg kg^{-1}) fraction at harvest

Levels	Ammoniacal nitrogen (mg kg^{-1})				
	Z_0	$Z_{2.5}$	Z_5	$Z_{7.5}$	Mean (N)
N_{100}	13.35	13.86	13.94	14.14	13.82
N_{150}	15.39	16.87	17.63	18.53	17.10
N_{200}	17.46	17.54	18.30	19.14	18.11
Mean (Z)	15.40	16.09	16.62	17.27	
	S.Em. (±)	CD (p=0.05)			
N	0.17	0.50			
Z	0.20	0.57			
N X Z	0.34	0.99			

**Control (No nitrogen, no zeolite) – 11.44 mg kg^{-1}*

The presence of zeolite in the soil inhibits nitrification process to a certain extent, so that nitrate leaching into deeper soil horizons is not so intensive. These results were comparable to the results obtained by Lija et al. [12], who found that treatment with compound fertilizer combined with zeolite showed highest NO_3-N while in compared to all other treatments. Mixing of an acid soil (Type:Paleudults) with clinoptilolite zeolite under waterlogged conditions significantly increased NO_3^- [16].

3.3 Nitrogen Recovery (%)

The data on N recovery of maize was presented in the Table 7. and Fig. 2. Irrespective of nitrogen levels, the N recovery was higher in the treatments receiving 7.5 t ha^{-1} of zeolite. The zeolite level $Z_{7.5}$ (7.5 t ha^{-1} of zeolite) recorded significantly higher N recovery (mean value - 70.37) compared to other zeolite levels. The next best N recovery was observed in the zeolite level Z_5 (5 t ha^{-1} of zeolite) *i.e.*, mean value - 62.10. Among the three levels of nitrogen, application of 200 kg ha^{-1} nitrogen registered significantly higher N recovery (mean value - 73.78) while application of 100 kg ha^{-1} nitrogen (N_{100}) resulted in lower N recovery (mean value - 58.01) among all the nitrogen levels. The interaction between nitrogen and zeolite had significantly affected N recovery of maize. The treatment receiving nitrogen @ 200 kg ha^{-1} along with 7.5 t ha^{-1} of zeolite ($N_{200}Z_{7.5}$) recorded higher N recovery (85.77) which was on par with $N_{200}Z_5$ (81.41). This was followed by $N_{150}Z_{7.5}$ (71.86).

The data on agronomic efficiency of maize was presented in the Table 8 and Fig. 3. Irrespective of nitrogen levels, the agronomic efficiency was higher in the treatments receiving 7.5 t ha^{-1} of zeolite. The zeolite level $Z_{7.5}$ (7.5 t ha^{-1} of zeolite) recorded significantly higher agronomic efficiency (mean value - 39.69) compared to other zeolite levels. The next best agronomic efficiency was observed in the zeolite level Z_5 (5 t ha^{-1} of zeolite) *i.e.*, 36.54 (mean value). Among the three levels of nitrogen, application of 200 kg ha^{-1} nitrogen registered significantly higher agronomic efficiency (mean value - 39.28) while application of 100 kg ha^{-1} nitrogen (N_{100}) resulted in lower agronomic efficiency (mean value - 24.99) among all the nitrogen levels. The interaction between nitrogen and zeolite had significantly affected agronomic efficiency of maize. The treatment receiving nitrogen @ 200 kg ha^{-1} along with 7.5 t ha^{-1} of zeolite ($N_{200}Z_{7.5}$) recorded higher agronomic efficiency (44.92) which was on par with $N_{200}Z_5$ (42.88). This was inturn on par with $N_{150}Z_{7.5}$ (39.40).

The main reason of zeolite significantly increasing NUE at different N application rates was due to the higher N uptake by maize. Slow-release of N fertilizer by zeolite after adsorption might be one of the reasons for improving N recovery and N use efficiency. The results obtained pertaining to NUE of maize were compatible with the results obtained by Ahmed et al. [8] who reported that the highest zeolite dose significantly increased N use efficiency of maize hybrid over treatment without zeolite. Application of zeolite in combination with N in rice improved N recovery and agronomic N use efficiency, Kavoosi [17]. Nitrogen use efficiency of sweet potato (*Ipomea batatus* L.) was highest in treatment containing 1% w/w Fly ash zeolite: soil as reported by Ramesh et al. [18].

Table 5. Effect of different levels of nitrogen (kg ha^{-1}) and zeolite (t ha^{-1}) application on nitrate nitrogen (mg kg^{-1}) fraction at 30, 60 and 90 DAS

	30 DAS					60 DAS					90 DAS				
Levels	**Z_0**	**$Z_{2.5}$**	**Z_5**	**$Z_{7.5}$**	**Mean (N)**	**Z_0**	**$Z_{2.5}$**	**Z_5**	**$Z_{7.5}$**	**Mean (N)**	**Z_0**	**$Z_{2.5}$**	**Z_5**	**$Z_{7.5}$**	**Mean (N)**
N_{100}	3.81	3.93	4.01	4.09	3.96	8.17	7.01	6.94	6.63	7.19	6.19	6.73	7.09	7.47	6.87
N_{150}	3.83	3.96	4.06	4.27	4.03	10.40	8.34	7.53	6.66	8.23	6.66	8.76	9.21	9.84	8.62
N_{200}	3.89	4.04	4.13	4.51	4.14	11.35	8.52	7.68	6.92	8.62	7.38	9.15	9.63	10.18	9.09
Mean (Z)	3.84	3.98	4.07	4.29		9.97	7.95	7.38	6.74		6.74	8.22	8.65	9.16	
*Control (No nitrogen, no zeolite) – 1.56 mg kg^{-1}						*Control (No nitrogen, no zeolite) – 5.34 mg kg^{-1}					*Control (No nitrogen, no zeolite) – 5.13 mg kg^{-1}				

	S.Em. (±)			CD (p=0.05)		
	30 DAS	**60 DAS**	**90 DAS**	**30 DAS**	**60 DAS**	**90 DAS**
N	0.03	0.06	0.19	0.10	0.18	0.56
Z	0.04	0.07	0.22	0.12	0.21	0.65
N X Z	0.07	0.12	0.38	NS	0.36	1.12

Table 6. Effect of different levels of nitrogen (kg ha^{-1}) and zeolite (t ha^{-1}) application on nitrate nitrogen (mg kg^{-1}) fraction at Harvest

Levels	Nitrate nitrogen (mg kg^{-1})				
	Z_0	$Z_{2.5}$	Z_5	$Z_{7.5}$	Mean (N)
N_{100}	3.76	3.88	3.90	3.95	3.87
N_{150}	4.27	4.63	4.82	5.05	4.69
N_{200}	4.78	4.80	4.99	5.20	4.94
Mean (Z)	4.27	4.44	4.57	4.73	
	S.Em. (±)	CD (p=0.05)			
N	0.04	0.12			
Z	0.05	0.14			
N X Z	0.09	0.25			

Control (No nitrogen, no zeolite) – 2.86 mg kg^{-1}

Table 7. Effect of different levels of nitrogen (kg ha^{-1}) and zeolite (t ha^{-1}) application on Nitrogen recovery (%)

Levels	*Nitrogen recovery (%)*				
	Z_0	$Z_{2.5}$	Z_5	$Z_{7.5}$	*Mean (N)*
N_{100}	*16.93*	*30.58*	*42.20*	*53.48*	*35.80*
N_{150}	*43.11*	*54.37*	*62.68*	*71.86*	*58.01*
N_{200}	*60.58*	*67.37*	*81.41*	*85.77*	*73.78*
Mean (Z)	*40.20*	*50.77*	*62.10*	*70.37*	
	S.Em. (±)	*CD (p=0.05)*			
N	*0.75*	*2.19*			
Z	*0.86*	*2.53*			
N X Z	*1.49*	*4.38*			

Table 8. Effect of different levels of nitrogen (kg ha^{-1}) and zeolite (t ha^{-1}) application on Agronomic efficiency (g grain g N applied^{-1}) of N

Levels	Agronomic efficiency (g grain g N applied^{-1})				
	Z_0	$Z_{2.5}$	Z_5	$Z_{7.5}$	Mean (N)
N_{100}	13.07	22.57	29.57	34.76	24.99
N_{150}	27.91	34.61	37.17	39.40	34.77
N_{200}	32.69	36.62	42.88	44.92	39.28
Mean (Z)	24.56	31.27	36.54	39.69	
	S.Em. (±)	CD (p=0.05)			
N	0.75	2.20			
Z	0.87	2.54			
N X Z	1.50	4.40			

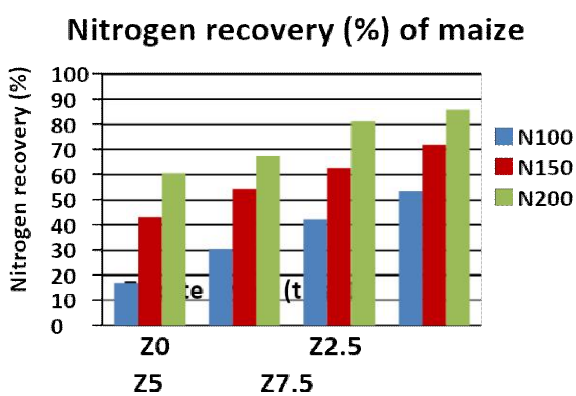

Fig. 2. Effect of different levels of nitrogen (kg ha^{-1}) and zeolite (t ha^{-1}) on Nitrogen recovery Agronomic efficiency of N (g grain g N applied^{-1})

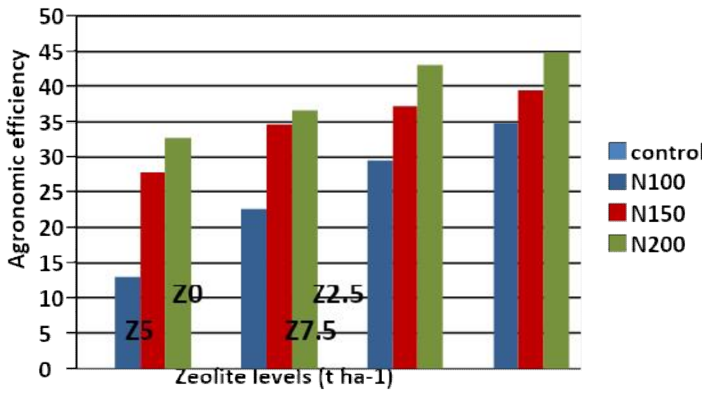

Fig. 3. Effect of different levels of nitrogen (kg ha^{-1}) and zeolite (t ha^{-1}) on agronomic efficiency of nitrogen

4. CONCLUSION

It was found that application of zeolite in combination with nitrogen have resulted in increased Nitrogen use efficiency of maize as well as it has significant impact on nitrogen fractions. N recovery showed an increasing trend with the increase of zeolite levels. The highest N recovery (85.77 %), agronomic use efficiency of nitrogen (44.92 g grain g N applied^{-1}) was obtained in $N_{200}Z_{7.5}$. The N uptake was highest in $N_{200}Z_{7.5}$. Hence it can be concluded that zeolite addition to soil in combination with nitrogen increased the availability of nutrients for timely utilization by the maize crop which resulted in increased nutrient uptake and nitrogen use efficiency of maize.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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