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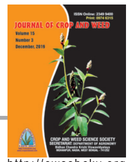

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Effect of different levels of nitrogen and zeolite on nutrient uptake and nitrogen use efficiency in rice

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ABTRACT

The pot culture experiment was conducted to investigate the effect of nitrogen and zeolite on nutrient content, uptake and nitrogen use efficiency in rice under greenhouse condition during wet season of 2018-19. The results showed that nitrogen, phosphorus and potassium content, uptake and nitrogen use efficiency in rice were increased with increasing nitrogen and zeolite levels. Higher nitrogen, phosphorus and potassium content and uptake in rice grain and straw was achieved with 120 kg N ha^{-1} and 9 t ha^{-1} zeolite due to more availability of nutrient in 120 kg N ha^{-1} and 9 t ha^{-1} zeolite interaction. Nitrogen recovery in rice by the application of zeolite and nitrogen in different levels was varied from 13.56 to 77.99 %.Highest nitrogen recovery in rice was 77.99% achieved by the application of 120 kg N ha^{-1} and 9 t ha^{-1}. Agronomical nitrogen use efficiency in rice was varies from 9.27 to 32.59 g grain g^{-1} N applied with the application of different levels of nitrogen and zeolite. N_3Z_4 interaction (120 kg N ha^{-1} and 9 t ha^{-1} zeolite) recorded highest agronomical nitrogen use efficiency in rice which was 32.59 g grain g^{-1} N applied. The result of present study indicates that nitrogen, phosphorus and potassium content, uptake in grain and straw were significantly increased with the use of 120 kg N ha^{-1} and 9 t zeolite ha^{-1}.

***Keywords*:** Nutrient uptake, nitrogen use efficiency, rice, zeolite

Rice is the most important staple food crop in India as well as in Telangana. Rice crop is mostly grown in humid, tropical and subtropical climate over wide range of soil and latitudes. Rice is only one among cereal crops which is survived in anaerobic soil condition because of its root system. Globally, rice occupies 159 Mha areas with 740 Mt productions (FAO, 2016). India is the highest rice producing country in the world having 43 M ha of land under rice cultivation. Production of rice in India is nearly 111 Mt and productivity is 2585 kg ha^{-1}. Population in our country is expected to reach 1.4 and 1.6 billion by 2025 and 2050 requiring annually 380 and 450 Mt of food grains respectively (Yadav *et al*., 2009).To fulfill the need of increasing population and to achieve high level of rice grain yield, rice required adequate amount of fertilizer. India contributes 23% share in global rice production and within country contribution of rice in total food grain production is near about 40-43% (Saha *et al*., 2017). Nitrogen played major role in green revolution for enhancing production of rice and helps in to fulfill the need of continuously increasing population.Today, the key factor for increasing cost of production is fertilizers. Year by year farmer applying recommended dose of fertilizer but nutrient use efficiency mainly in rice crop is low (Peng *et al*., 2006). Farmer in India mostly gives more preference to urea compared to other fertilizer for paddy crop because urea contained 46 % N which is more than other fertilizer. Nitrogen use efficiency in paddy is only 30-40% (Thind *et al*., 2016) and other 60-70 % of nitrogen escape through various processes occurred in soil. These are major constraints in paddy productivity. Main reason for low efficiency is losses of nitrogen through leaching, volatisation and denitrification process (Shivay *et al*., 2005). Agronomic efficiency for nitrogen is about 13 kg per 1 kg N in paddy crop. The nitrogen recovery rate is increased by one percent consumption of urea which will be declined by 1.5 mt per year. Nitrogen use efficiency in paddy field can be increased by declining nitrogen losses through various processes with the application of proper fertilizer at proper time and by proper method. Zeolite also has capacity to improve NUF by restricting different losses of N from soil.The unique properties of zeolites are more CEC, adsorption, and internal surface area, water holding capacity, having more canals, cavities and micro pores. Zeolite can be used as soil amendments, slow-release fertilizer and other materials in agriculture (Mumpton and Fishman, 1977). The recovery of nitrogen fertilizer is low in rice. Zeolite mineral has capacity to improve CEC of soil when it is applied as soil ameliorants (DeSutter and Pierzynski, 2005). High CEC of zeolite

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and more selectivity of NH_4^+ toward zeolite can help in reduction of leaching (DeLuca and DeLuca, 1997), denitrification and ammonia volatisation losses in coarse textured and low land rice soil. Zeolite mineral is also stored NH_4+ in canal and cavity network. NH_4 ion in zeolite is released slowly which is continuously uptook by plant for more yield and it also help in improving NUE in rice crop. By considering this information, the pot culture experiment was conducted to study the effect of different levels of nitrogen and zeolite on nutrient content, uptake and nitrogen use efficiency in rice under greenhouse condition.

MATERIALS AND METHODS

The present pot culture experiment was conducted during 2018-19 in wet season in green house of Department of Soil Science and Agricultural Chemistry, College of Agriculture, Rajendranagar, Hyderabad which is located between $78^0 43'$ E longitude and $17^0 31'$ N latitude, at an altitude of 542.6 m above mean sea level. This experiment was conducted to study the effect of different levels of nitrogen and zeolite on nutrient content, uptake and nitrogen use efficiency in rice.The soil was classified as a sandy loam. Physical and chemical analyses were performed in a depth range of 0–0.15m for the initial characterization of the area (Table 1).The experiment was laid out in completely randomized design with factorial concept, having three levels of nitrogen (60, 90 and 120 kg N ha^{-1}) and four levels of zeolite (0, 3, 6 and 9 t ha^{-1}) and replicated thrice. The experiment was undertaken with thirteen treatment combinations. Nitrogen and zeolite were applied as per treatment combinations. Zeolite (sodium form) powder used in experiment was collected from ACME chemicals, Borivalli west, Mumbai. The properties of zeolite are given in Table 2. Rice seed @ 50 kg ha^{-1} was soaked in water for 24 hours and incubated for 48 hrs. in gunny bag for sprouting.These seeds were broadcasted in well prepared, levelled and raised seedbed. Twenty-five days old seedlings were transplanted in pot contained eight kg of soil and zeolite. Total three hills were made in each pot and in each hill, two seedlings were transplanted. After transplanting of paddy seedlings, 2-3 cm of water was maintained in pots up to tillering stage and there after 5 cm of water was maintained up to dough stage. After dough stage, excess water from pots was drained to increased grain yield. Rice crop needed 120-60-40 kg N, P_2O_5, K_2O ha^{-1} to achieve proper growth and highest yield in Telangana (PJTSAU, 2018-19). These NPK doses were converted into eight-kilogram soil and applied through urea, single super phosphate and muriate of potash respectively. In whole experiment, P and K doses remained uniform, only the N doses were changed as per treatment. Grain and straw sample collected at harvest were dried in oven at 65°C temperature.The dried samples were made in to fine ground powdered for N, P and K analysis. For Nitrogen, grain and straw were digested with conc. H_2SO_4 and H_2O_2. Nitrogen content in extracts was estimated by Micro kjeldahl method (Jackson, 1973) and expressed in percentage. Grain and straw were digested with triacid mixture (HNO_3:H_2SO_4:$HClO_4$ in ratio of 9:4:1) for 24 hours until liquid in that flask was colourless. This diluted digest was used for determination of P and K content in plant sample. Phosphorus content was determined by using vandomolybdate method (Jackson, 1973). Potassium content were determined by using flame photometer method (Jackson, 1973). Nitrogen, phosphorus and potasium uptake in plant was determined by following formula:

$$\text{N, P and K uptake in plant} = \frac{\text{Concentration of N, P and K in per cent grain yield or straw yield (g pot}^{-1})}{100}$$

N, P and K uptake in plant was expressed in mg pot^{-1}

Nitrogen use efficiency is a parameter which indicates the amount of N uptake by plant to applied N. Nitrogen use efficiency was calculated by different parameters (Yadav *et al.*,2017). These parameters are as followed,

$$\text{Apparent N recovery (\%)} = \frac{\text{NUF} - \text{NUC}}{\text{AF}} \times 100$$

$$\text{Agronomic N use efficiency (g grain g}^{-1}\text{N applied)} = \frac{\text{GYF} - \text{GYC}}{\text{AF}}$$

Where ,

NUF -: Total uptake of nitrogen from respective fertilized pot.

NUC-:Total uptake of nitrogen from control pot.

GYF-:Grain yield from respective fertilized pot.

GYC -:Grain yield from control pot.

AF- : Applied fertilizer (urea)

The data emerged out from pot culture experiment was statistically analyzed using Fisher method of ANOVA for FCRD given by Gomez and Gomez (1984). The data obtained after statistical analysis was used to evaluate the treatment effects.

Table 1: Important physical, physico-chemical and chemical properties of the studied soil

Sl.No.	Determination	Value	Method	Reference
A		**Physical properties**		
1	Particle size analysis		Hydrometer method	Piper(1966)
	Sand (%)	74.80		
	Silt (%)	20.00		
	Clay (%)	5.20		
	Texture	Sandy loam		
2	B.D (Mg M^{-3})	1.50	Cylindrical core method	Blake and Hartage (1986)
3	WHC (%)	37.19	Keen box method	Jackson (1967)
B.		**Physico-chemical properties**		
1. 1	pH	6.64	Potentiometry	Jackson (1973)
2. 2	EC (dSm^{-1})	0.51	Conductometry	Jackson (1973)
3. 4	CEC (cmol (p+) kg^{-1})	13.41	Sodium acetate method	Sumner and Miller (1996)
C		**Chemical properties**		
1. 3	Organic carbon (g kg^{-1})	7.50	Rapid titration method	Nelson and Sommers (1982)
2. 1	Available N (kg ha^{-1})	127	Alkaline $KMNO_4$	Subbiah and Asija (1956)
3. 2	Ammonium N (mg kg $^{-1}$)	4.21	Magnesium oxide	Bremmer (1965)
4. 3	Nitrate N (mg kg $^{-1}$)	0.36	Devardas alloy	Bremmer (1965)
5. 2	Available P_2O_5 (kg ha $^{-1}$)	17.00	Olsen's method 0.5 M $NaHCO_3$ pH 8.5	Olsen *et al.*(1954)
6. 3	Available K_2O(kg ha $^{-1}$)	218	Neutral N NH_4OAc	Jackson (1973)

Treatment combination

Treatment	Zeolite (t ha^{-1})	Nitrogen (Kg ha^{-1})	Phosphorus (Kg ha^{-1})	Potassium (Kg ha^{-1})
T_1	0	0	0	0
T_2	0	60	60	40
T_3	3	60	60	40
T_4	6	60	60	40
T_5	9	60	60	40
T_6	0	90	60	40
T_7	3	90	60	40
T_8	6	90	60	40
T_9	9	90	60	40
T_{10}	0	120	60	40
T_{11}	3	120	60	40
T_{12}	6	120	60	40
T_{13}	9	120	60	40

Table 2: Zeolite (Sodium form) properties

Sr.No.		Standard value
A	**Chemical composition (%)**	
1.	SiO2	82
2.	Al2O3	8
3.	Na2O	1.5
4.	CaO	0.5
5.	TiO2	0.3

Contd.

Table 2 Contd.

Sr. No.		Standard value
B.	**Physical properties**	
1.	Water holding capacity(%)	100
2.	Bulk density (Mg M^{-3})	0.4
3.	Pore Size (micron) and Pore Volume (%)	
	Less than 0.1 ì	23
	0.1 to 1.0 ì	33
	1.0 to 2.0 ì	23
	2.0 to 4.0 ì	13
	4.0 to 6.0 ì	01.
	20.0 50.0 ì	0.7
C.	**Chemical properties**	
1.	pH	8.5
2.	EC(dS m^{-1})	0.61
3.	CEC (cmol (p^+) kg^{-1})	130

RESULTS AND DISCUSSION

Nitrogen content in rice

Nitrogen content in grain was significantly affected by different levels of nitrogen and zeolite according to Table 3. Highest nitrogen content in grain has been recorded in N_3 level @ 120 kg N ha $^{-1}$ which was significantly superior over N_2 level @ 90 kg N ha $^{-1}$ and N_1 level @ 60 kg N ha $^{-1}$ while in case of different zeolite levels, Z_4 level @ 9 t ha^{-1} recorded highest nitrogen content in grain which was significantly superior over other zeolite levels according to Table 3. Table 3 showed that highest nitrogen content in rice grain was 1.11 % in N_3Z_4 interaction. Nitrogen content in straw at harvest was significantly affected by different levels of nitrogen and zeolite application. Similar result of nitrogen content in straw was observed in rice based on Table 3. Highest nitrogen content in grain and straw was recorded in N_3Z_4, N_3Z_3 and N_2Z_4 level compared to other levels because of more availability of nitrogen at different growth stages. This is might be due to slow release of nitrogen and less leaching loss of nitrogen at different growth stages (Aghaalikhani *et al*., 2012). Ahmed *et al*. (2010) revealed that application of zeolite 540 g with 1.50 g of urea treatment recorded highest nitrogen content in plant tissue compared to control treatment due to improved nitrogen concentrations in the soil because the zeolite also has the ability to adsorb nitrogen from the fertilizers used as well as reducing leaching in the soil. Wu *et al*. (2016) reported that application of zeolite at 7.5 t hm^{-2} with 78.75 kg hm^{-2} to 157.5 kg hm^{-2} nitrogen resulted higher nitrogen accumulation in rice.

Phosphorus content in rice

Nitrogen and zeolite levels showed significant effect on phosphorus content in grain and straw, but their interaction showed non-significant effect on phosphorus content in grain only based on Table 4. Highest phosphorus content in grain and straw was observed in N_3Z_4 followed by N_3Z_3 and N_2Z_4 levels due to more availability of phosphorus in soil at grain formation and grain filling stage. Availability of phosphorus content in soil was increased due to solubility effect of zeolite (Jing *et al*., 2016) while nitrogen levels also increases phosphorus content in plant due to synergistic effect between phosphorus and nitrogen. In different levels of zeolite, highest phosphorus content in grain and straw was observed in Z_4 @9 t ha^{-1} level which was significantly superior over other zeolite levels while in different nitrogen levels, highest phosphorus content in grain and straw was obtained in N_3 level @120 Kg N ha^{-1} which was significantly superior over other nitrogen levels. Ahmed *et al.* (2010) revealed that phosphorus content in different parts of plant viz. stem, leaves and roots was non-significantly increased by zeolite addition.

Potassium content in rice

The data showed that application of nitrogen and zeolite recorded significantly higher potassium content in grain and straw (Table 5). The maximum potassium content in grain and straw was observed in N_3Z_4 interaction. Amongst nitrogen level, highest potassium content in grain and straw was observed in N_3 level @ 120 Kg ha^{-1} which was significantly superior over remaining treatments. Amongst different zeolite levels, Z_4 levels @ 9 t ha^{-1} containing rice plant recorded significantly higher potassium content in grain and straw followed by Z_3 @ 6 t ha^{-1} and Z_2 @ 3t ha^{-1}. Potassium content in grain and straw was increased with increasing nitrogen levels because of synergetic effect between nitrogen and potassium. Zeolite also increases potassium content in grain and straw might be due to more availability of potassium in soil because of slow release of potassium from zeolite surface and canal networks (Filcheva and Tsadilas, 2002). However, more adsorption, absorption and less leaching loss of potassium increased availability of potassium in soil at panicle initiation, grain formation and grain filling stages which ultimately increased the absorption and content of potassium in grain and straw. The results support the findings of Gholamhoseini *et al*. (2012), Junxi *et al*. (2013) and Ahmed *et al*. (2010).

Nitrogen uptake in rice

Nitrogen uptake in rice grain was significantly increased by the nitrogen and zeolite interaction. Highest nitrogen uptake in rice grain was observed in N_3Z_4 interaction level which was significantly superior over other interaction levels presented in Table 5 while lowest nitrogen uptake in grain was recorded in N_1Z_1 level. Table 5 showed that highest nitrogen uptake in rice grain in the sense of individual factor was observed in N_3 level @ 120 kg N $ha^{-1}$and Z_4 level @ 9 t ha $^{-1}$. In rice straw, nitrogen uptake was increased by the interaction of nitrogen and zeolite significantly. As like rice grain, similar nitrogen uptake pattern was recorded in rice straw. Nitrogen uptake in grain and straw was depended upon the availability of nitrogen in soil. Highest nitrogen uptake was observed by the application of 120 kg ha^{-1} nitrogen and 9 t ha^{-1} zeolite. The availability of nitrogen in soil was increased due to its absorption in zeolite canal and less leaching of nitrogen from soil.Nitrogen availability in soil was also increased due to slow release of absorbed nitrogen from zeolite canals.Compared to other nitrogen and zeolite levels, N_3 level @ 120 kg ha^{-1} and Z_4 level @ 9 t ha^{-1} recorded highest nitrogen uptake in rice grain and straw might be due to more availability of nitrogen in soil. Taotao *et al*. (2017) reported that nitrogen applied at 52.5, 105 and 157 kg ha^{-1} increased nitrogen uptake by 60.1, 124.5 and 163.4% respectively, over control while zeolite applied at 5,10 and 15 t ha^{-1} enhanced N uptake by 18.3, 37.7 and 49.5% respectively over control. Wu *et al*. (2016) also noted Nitrogen accumulations in rice were increased with increasing nitrogenrate from 75.75 kg hm^{-2} to 157.5 kg hm^{-2}. Highest nitrogen accumulation in rice was observed in7.5 t hm^{-2} zeolite +157.5 kg hm^{-2} nitrogen (0.750 g pot^{-1}). The result of present study agrees with Malekian *et al*. (2011) who revealed that nitrogen uptake was significantly increased with increasing nitrogen and zeolite levels.

Phosphorus uptake in rice

Phosphorus uptake in grain was significantly influenced by nitrogen and zeolite interaction (Table 6). Phosphorus uptake in grain was increased might be due to synergetic interaction between nitrogen and phosphorus and also due to the increase of phosphorus in soil with the application of zeolite. Highest phosphorus uptake in grain was recorded in N_3Z_4 interaction i.e., 120 Kg N ha^{-1} and 9 t ha^{-1} zeolite according to Table 3. In the sense of individual factor, highest phosphorus uptake in grain was recorded in N_3 level,i.e., 120 Kg N ha^{-1} and Z_4 i.e., level 9 t ha^{-1} zeolite. The percent phosphorus uptake in grain at harvest was in N_3 level @ 120 kg ha^{-1} at Z_2, Z_3 and Z_4levels over Z_1 level. Similar pattern of phosphorus uptake in straw was observed. Compared to rice straw, more phosphorus uptake was recorded in rice grain. Phosphorus uptake in grain and straw was increased with increasing nitrogen levels may be due to synergetic effect of nitrogen on phosphorus uptakes while zeolite also increased phosphorus uptake might be due to solubilization effect of phosphorus in soil. Phosphorus uptake in rice is mostly depended on adequate content of available phosphorus in soil which can be increased due to submerged condition in pot and solubilization effect of zeolite on soil phosphorus. In submerged condition, micronutrients like Fe, Mn, Zn and Cu are present in reduced form which is precipitated with OH^- ion and CO_3^- and decreases the affinity of micronutrient toward phosphorus, ultimately increases availability of soil phosphorus while zeolite has more CEC which can adsorb present micronutrient in soil and reduces the transformation of available form of phosphorus to unavailable form or soluble form to insoluble form (Jing *et al*., 2016). This mechanism of zeolite increases phosphorus availability uptake in rice. Similar result was obtained by Ahmed *et al*. (2010), Amirhossein *et al*. (2015) and Hasbullah *et al*. (2015).

Potassium uptake in rice

Potassium uptake in grain and straw of rice was significantly influenced by the nitrogen and zeolite application (Table 7). Potassium uptake in grain was lower than straw. Significantly highest potassium uptake in grain was observed in N_3Z_4 interaction. Among nitrogen levels, highest potassium uptake in grain was recorded in N_3 level @ 120 kg N ha^{-1}and among four different zeolite levels, highest potassium uptake in grain was recorded in Z_4 level @ 9 t ha^{-1}. Similar results were recorded in rice straw. Potassium uptake in rice was increased might be due to more availability of potassium in soil. Application of zeolite at different levels increased cation exchange capacity of soil which is responsible to more availability of potassium in soil. Leaching of potassium in soil was reduced due to the zeolite application because of storage of potassium in zeolite canal network structure which significantly improved the potassium availability of soil. Highest potassium uptake was recorded in Z_4 level followed by Z_3 and Z_2 levels over Z_1 level because of more adsorption of potassium and less leaching of potassium in soil which can increase potassium availability in soil. Potassium uptake in rice was increased due to synergistic effect of nitrogen. Ahmed *et al.* (2010) reported that regardless of plant portion (leaves, stem and roots), treatment with zeolite significantly improved N, P and K uptake compared with control. Similar results were also obtained by Ghiri (2014).

Nitrogen recovery

Nitrogen recovery in rice was increased with zeolite application significantly presented in Table 8. Nitrogen recovery of rice in different interaction levels varied from 13.56 % - 77.99 %. Among the interaction effects, interaction of N_3Z_4 recorded highest nitrogen recovery in rice while in individual nitrogen and zeolite levels, highest nitrogen recovery in rice was observed in N_3 level @ 120 kg N ha^{-1} and Z_4 level @ 9 t ha^{-1}. The result of present study revealed that nitrogen recovery in rice was increased with increasing nitrogen and zeolite level. Highest nitrogen recovery in rice at particular nitrogen level was recorded in Z_4 level (9 t ha^{-1}) followed by Z_3 (6 t ha^{-1}), Z_2 (3 t ha^{-1}) compared to Z_1 because of less leaching of nitrate and ammonical ion, slow release of absorbate and adsorbate ammonical ion from zeolite canal into soil solution and reduced the transformation of ammonical nitrogen form to nitrate nitrogen form. Nitrogen recovery efficiency was increased with increasing zeolite and nitrogen rates. At 8 t ha^{-1} zeolite dose, highest NRE was found in 80 kg N ha^{-1} (84.4 %) compared to 20(50.8 %) and 40 kg ha^{-1} (66.2 %) nitrogen application rate with same zeolite dose. At 80 kg ha^{-1} N, highest NRE was found in 8 t ha^{-1}zeolite level (84.4%) followed by 4 t ha^{-1}zeolite level (74.3 %) and 2 t ha^{-1} zeolite level,i.e.,67.8% (Sepaskhah and Barzegar, 2010). Similar results were also obtained byAghaalikhani *et al.* (2012). They found highest nitrogen uptake efficiency in $N_{270}Z_9$ treatment (54%) while lowest nitrogen uptake efficiency was recorded in $N_{90}Z_9$(14%). Kavoosi (2007) also observed significant effect on nitrogen recovery in rice with zeolite application. Highest nitrogen recovery percentage in rice was recorded in 8 t ha^{-1} zeolite + 60 Kg ha^{-1} nitrogen on par with 16 t ha^{-1}zeolite + 60 Kg ha^{-1} nitrogen (65% in whole plant, 43% in grain and 20% in straw) compared to control (Kavoosi, 2007). Wu *et al*. (2016) also revealed that nitrogen recovery was increased with increasing zeolite doses.

Agronomical Nitrogen use efficiency

According to Table 9 interaction of different levels of N × Z influenced significant effect on agronomical NUE in rice. Agronomical NUE of rice in different interaction levels varied from 9.27 - 32.59 g grain g^{-1} N applied. Highest agronomical NUE in rice was recorded in N_3 level @ 120 kg N ha^{-1} (25.95 g grain g^{-1} N applied) and Z_4 level @ 9 t ha^{-1}. Among the interaction effects, interaction of N_3Z_4 level recorded highest agronomical NUE in rice followed by N_3Z_3 level and N_2Z_4 level which was superior to other interaction levels.

Agronomical nitrogen use efficiency was increased with increasing nitrogen and zeolite levels due to less leaching of nitrogen during panicle initiation stage to grain filling stage that might be increases availability and uptake of nitrogen. Taotao *et al*. (2017) reported that Nitrogen recovery efficiency was reduced from 0.51 – 0.46 Kg NKg^{-1} by increasing application dose from 52.5- 105 Kg N ha^{-1} while NRE was improved up to 61.1- 121.4% when zeolite applied at 10- 15 t ha^{-1}. The result of present study agrees with Sepaskhah and Barzegar (2010) who revealed that application of nitrogen along with zeolite significantly increased agronomical nitrogen use efficiency in rice. Agronomical nitrogen use efficiency was improved because of less leaching or other losses of nitrate and ammonical form of nitrogen by the application of zeolite which probably increases the uptake of nitrogen in rice. Sepaskhah and Yousefi (2007) revealed that application of zeolite at different doses significantly reduced ammonical and nitrate losses through leaching process that improved the availability in soil and also uptake in rice.

Table 3: Effect of different levels of nitrogen, zeolite and their interaction on nitrogen content in rice grain and straw (%)

Levels	Nitrogen content (%)									
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
	Z_1 : 0		Z_2: 3 t ha^{-1}		Z_3: 6 t ha^{-1}		Z_4: 9 t ha^{-1}		Mean	
N_1: 60 Kg ha^{-1}	0.64	0.49	0.68	0.54	0.71	0.57	0.85	0.71	0.72	0.58
N_2: 90 Kg ha^{-1}	0.74	0.60	0.77	0.62	0.81	0.65	0.99	0.80	0.83	0.67
N_3:120Kg ha^{-1}	0.92	0.74	0.95	0.77	1.07	0.87	1.11	0.91	1.01	0.83
Mean	0.77	0.61	0.80	0.64	0.86	0.70	0.98	0.81		

	SEm (±)		LSD (0.05)	
	Grain	Straw	Grain	Straw
N	0.004	0.01	0.01	0.01
Z	0.005	0.01	0.01	0.02
N × Z	0.008	0.01	0.02	0.03

Control – 0.59 % in grain and 0.45 % in straw (No nitrogen and zeolite application)

Table 4: Effect of different levels of nitrogen, zeolite and their interaction on phosphorus content in rice grain and straw (%)

Levels	Phosphorus content (%)									
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
	Z_1 : 0		Z_2: 3 t ha^{-1}		Z_3: 6 t ha^{-1}		Z_4: 9 t ha^{-1}		Mean	
N_1: 60 Kg ha^{-1}	0.18	0.07	0.20	0.09	0.21	0.10	0.24	0.12	0.21	0.10
N_2: 90 Kg ha^{-1}	0.22	0.08	0.24	0.11	0.25	0.11	0.27	0.14	0.25	0.11
N_3:120Kg ha^{-1}	0.23	0.10	0.26	0.13	0.27	0.14	0.30	0.16	0.27	0.13
Mean	0.21	0.08	0.23	0.11	0.25	0.12	0.27	0.14		

	SEm (±)		LSD (0.05)	
	Grain	Straw	Grain	Straw
N	0.002	0.001	0.006	0.003
Z	0.002	0.001	0.007	0.004
N × Z	0.004	0.002	NS	0.007

Control – 0.14 % in grain and 0.04 % in straw (No nitrogen and zeolite application)

Table 5: Effect of different levels of nitrogen, zeolite and their interaction on potassium content in rice grain and straw (%)

Levels	Potassium content (%)									
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
	Z_1 : 0		Z_2: 3 t ha^{-1}		Z_3: 6 t ha^{-1}		Z_4: 9 t ha^{-1}		Mean	
N_1: 60 Kg ha^{-1}	0.54	1.17	0.56	1.20	0.59	1.23	0.62	1.26	0.58	1.21
N_2: 90 Kg ha^{-1}	0.62	1.27	0.64	1.30	0.66	1.33	0.74	1.41	0.66	1.33
N_3:120Kg ha^{-1}	0.68	1.35	0.71	1.38	0.78	1.46	0.78	1.46	0.74	1.41
Mean	0.61	1.26	0.64	1.29	0.68	1.34	0.71	1.38		

	SEm (±)		LSD (0.05)	
	Grain	Straw	Grain	Straw
N	0.003	0.003	0.007	0.008
Z	0.003	0.003	0.008	0.010
N × Z	0.005	0.005	0.015	0.017

**Control – 0.49 % in grain and 1.12 % in straw (No nitrogen and zeolite application)*

Table 6: Effect of different levels of nitrogen, zeolite and their interaction on nitrogen uptake in rice grain and straw (mg pot $^{-1}$)

Levels	Nitrogen uptake (mg pot $^{-1}$)									
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
	Z_1 : 0		Z_2: 3 t ha^{-1}		Z_3: 6 t ha^{-1}		Z_4: 9 t ha^{-1}		Mean	
N_1: 60 Kg ha^{-1}	39.99	46.90	48.38	56.32	53.77	59.28	70.36	96.92	53.12	64.86
N_2: 90 Kg ha^{-1}	75.49	85.49	87.93	88.76	108.07	105.84	141.36	147.52	103.21	106.90
N_3:120Kg ha^{-1}	112.32	114.77	126.24	125.61	191.92	175.08	203.29	193.31	158.44	152.19
Mean	75.93	82.39	87.52	90.23	117.92	113.40	138.34	145.92		

	SEm (±)		LSD (0.05)	
	Grain	Straw	Grain	Straw
N	0.93	1.25	2.74	3.67
Z	1.08	1.44	3.16	4.23
N × Z	1.87	2.5	5.48	7.33

**Control – 25.36 mg pot $^{-1}$ in grain and 33.054 mg pot $^{-1}$ in straw (No nitrogen and zeolite application)*

Table 7: Effect of different levels of nitrogen, zeolite and their interaction on phosphorus uptake in rice grain and straw (mg pot^{-1})

Levels	Phosphorus uptake (mg pot $^{-1}$)									
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
	Z_1 : 0		Z_2: 3 t ha^{-1}		Z_3: 6 t ha^{-1}		Z_4: 9 t ha^{-1}		Mean	
N_1: 60 Kg ha^{-1}	11.04	6.98	14.00	9.44	16.08	10.40	19.89	16.45	15.25	10.82
N_2: 90 Kg ha^{-1}	22.69	10.87	27.79	15.40	33.95	18.00	38.89	26.53	30.83	17.70
N_3:120 Kg ha^{-1}	27.75	15.44	34.54	20.66	49.18	28.67	55.54	33.87	41.75	24.66
Mean	20.49	11.09	25.44	15.16	33.07	19.02	38.11	25.62		

	SEm (±)		LSD (0.05)	
	Grain	Straw	Grain	Straw
N	0.33	0.18	0.96	0.53
Z	0.38	0.21	1.11	0.61
N × Z	0.65	0.36	1.92	1.06

**Control – 5.88 mg pot $^{-1}$ in grain and 3.18 mg pot $^{-1}$ in straw (No nitrogen and zeolite application)*

Table 8: Effect of different levels of nitrogen, zeolite and their interaction on potassium uptake in rice grain and straw (mg pot $^{-1}$)

Levels	Potassium uptake (mg pot $^{-1}$)									
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
	Z_1 : 0		Z_2: 3 t ha^{-1}		Z_3: 6 t ha^{-1}		Z_4: 9 t ha^{-1}		Mean	
N_1: 60 Kg ha^{-1}	33.74	111.22	39.85	125.85	44.47	127.87	51.33	172.74	42.34	134.42
N_2: 90 Kg ha^{-1}	62.96	179.97	73.08	187.70	88.43	217.67	105.30	261.09	82.44	211.61
N_3: 120 Kg ha^{-1}	83.30	208.41	94.33	225.12	140.35	292.28	142.84	309.06	115.21	258.72
Mean	59.99	166.53	69.09	179.55	91.08	212.61	99.82	247.63		

	SEm (±)		LSD (0.05)	
	Grain	Straw	Grain	Straw
N	0.58	1.53	1.72	4.51
Z	0.67	1.77	1.98	5.20
N × Z	1.17	3.07	3.43	9.01

* *Control- 21.05 mg pot $^{-1}$ in grain and 82.28 mg pot $^{-1}$ in straw (No nitrogen and zeolite application)*

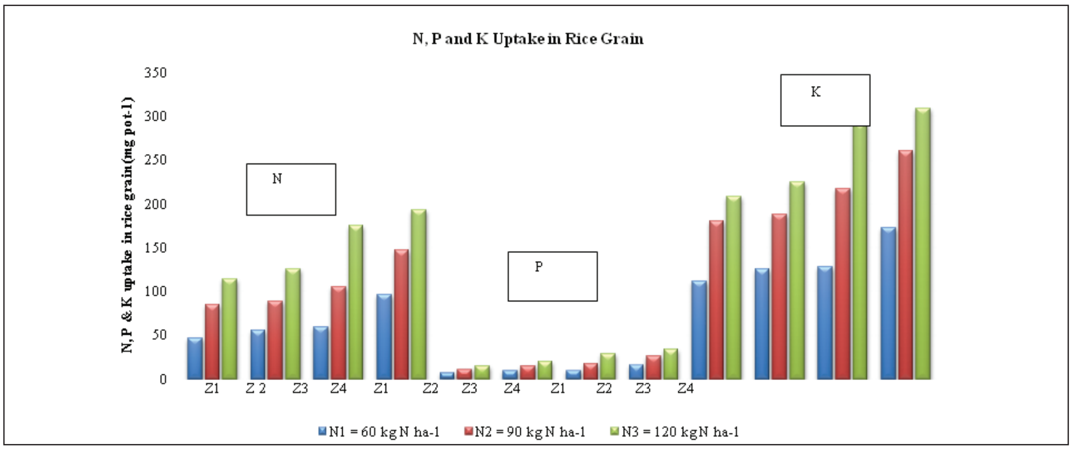

Fig.1: Effect of different levels of nitrogen and zeolite on nitrogen, phosphorus and potassium uptake in rice grain (mg pot $^{-1}$)

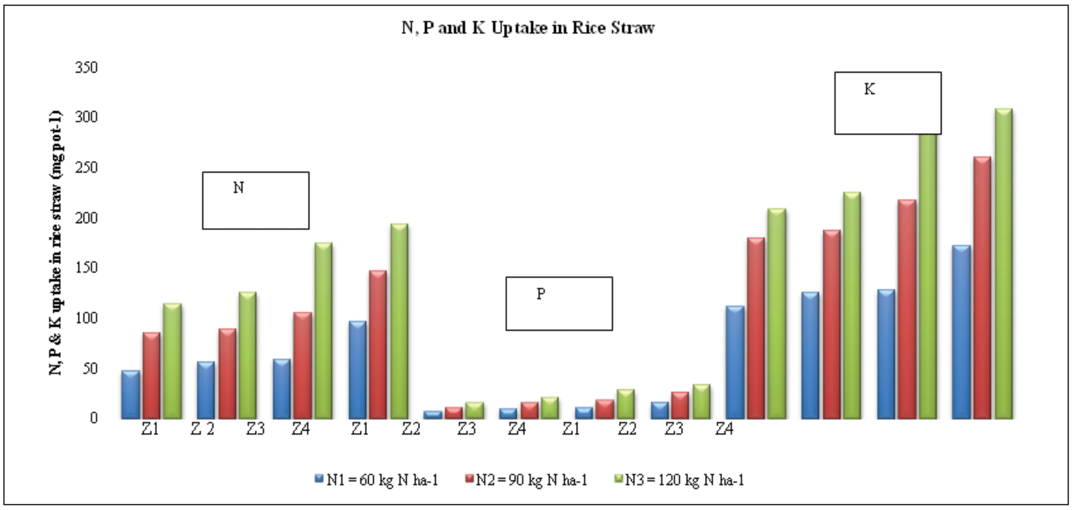

Fig.2: Effect of different levels of nitrogen and zeolite on nitrogen, phosphorus and potassium uptake in rice straw (mg pot^{-1})

Table 9: Effect of different levels of nitrogen, zeolite and their interaction on nitrogen recovery in rice (%)

Levels	Nitrogen recovery (%)				
	Z_1	Z_2	Z_3	Z_4	mean
N_1	13.56	22.04	26.02	51.84	28.36
N_2	32.05	36.96	48.59	72.12	47.43
N_3	39.22	44.99	73.65	77.99	58.96
Mean	28.28	34.66	49.42	67.31	
	SEm (±)	**LSD (0.05)**			
N	0.47	1.39			
Z	0.54	1.6			
N × Z	0.94	2.77			

Table 10: Effect of different levels of nitrogen, zeolite and their interaction on agronomical nitrogen use efficiency in rice (g grain g^{-1} N applied).

Levels	Agronomical NUE (g grain g^{-1} N applied)				
	Z_1	Z_2	Z_3	Z_4	Mean
N_1	9.27	13.41	15.40	18.95	14.26
N_2	18.30	22.25	28.43	31.03	25.00
N_3	18.49	20.90	32.06	32.59	25.95
Mean	15.35	18.85	25.30	27.52	
	SEm (±)	**LSD (0.05)**			
N	0.56	1.17			
Z	0.65	1.35			
N × Z	1.13	2.34			

From present study, it is revealed that combined application of zeolite and nitrogen improved the nutrient uptake and nitrogen use efficiency in rice. Highest nitrogen, phosphorus and potassium content and uptake in rice grain and straw were achieved in N_3, Z_4 and N_3Z_4 interaction. Rice achieved highest nitrogen use efficiency (77.79 % Nitrogen recovery and 32.59 g grain g^{-1} N applied) in 120 Kg N ha^{-1} with 9 t ha^{1} zeolite treatment. So, it is expected that if our trials can be validated at field level, similar performance can be achieved. Combine application of 120 Kg N ha^{-1} and 9 t ha^{1} zeolite is recommended for better rice performance.

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