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Effect of zeolite and potassium application on nutrient uptake and potassium use efficiency of maize

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Abstract
The present investigation was undertaken to study the effect of zeolite and potassium application on nutrient uptake and potassium use efficiency of maize. The field experiment was conducted at Post Graduate Institute, Research Farm, Department of Soil Science and Agricultural Chemistry, M.P.K.V., Rahuri, during of summer 2022. The experimental site was medium deep black, clayey in texture, having a bulk density of 1.35 Mg m^{-3}, particle density of 2.65 Mg m^{-3}, slightly alkaline in reaction, low in electrical conductivity and medium in organic carbon and calcium carbonate content. The soil was low in available Nitrogen, medium in phosphorus and very high in potassium content. However, soils were sufficient in available micronutrients *viz.*, Fe, Mn, Zn and Cu.
The experiment was laid out in a randomized block design with ten treatments and three replications. The treatments were T_1: Absolute control, T_2: GRDF 120:60:40 N, P_2O_5, K_2O + 10 t FYM ha^{-1}, T_3: Zeolite @ 400 kg ha^{-1}, T_4: Zeolite @ 600 kg ha^{-1}, T_5: Zeolite @ 400 kg ha^{-1} + 50% K_2O of RDF (20 kg ha^{-1}), T_6: Zeolite @ 400 kg ha^{-1} + 75% K_2O of RDF (30 kg ha^{-1}), T_7: Zeolite @ 400 kg ha^{-1} + 100% K_2O of RDF (40 kg ha^{-1}), T_8: Zeolite @ 600 kg ha^{-1} + 50% K_2O of RDF (20 kg ha^{-1}), T_9: Zeolite @ 600 kg ha^{-1} + 75% K_2O of RDF (30 kg ha^{-1}), T_{10}: Zeolite @ 600 kg ha^{-1} + 100% K_2O of RDF (40 kg ha^{-1}). The recommended doses of N and P_2O_5 and FYM @ 10 t ha^{-1} are the same for all treatments as per RDF except T_1.
The Application of zeolite @ 600 kg ha^{-1} along with the RDF, that is treatment T_{10} showed significantly highest grain yield (83.22 q ha^{-1}), stover yield (52.89 q ha^{-1}), cob weight (84.22 q ha^{-1}), seed index (38.28 gm) and number of grains per cob (722) over the rest of treatments except T_9 i.e., zeolite @ 600 kg ha^{-1}+ 75% K_2O of RDF which was statistically at par.
The total uptake of N, P, K and micronutrients (Fe, Mn, Zn, Cu) by maize was significantly influenced by the different levels of zeolite and potassium application after harvest of maize. Significantly, the highest uptake of N, P and K (213.30, 23.16 and 140.24 kg ha^{-1} respectively) and Fe, Mn, Zn and Cu (2548.83, 1210.53, 913.27 and 141.87 mg kg^{-1} respectively) was observed in the treatment T_{10} i.e., zeolite @ 600 +100% K_2O of RDF (40 kg ha^{-1}) over rest of treatments except T_9 i.e., zeolite @ 600 kg ha^{-1}+ 75% K_2O of RDF which was statistically at par with T_{10} in respect to nitrogen and phosphorous but in case of potassium treatment T_7 i.e., zeolite @400 kg ha^{-1} along with RDF is found to be statistically at par with treatment T_{10}. Application of zeolite to hybrid maize found beneficial for increase in nutrient uptake of maize.

Keywords: Maize, SOP, MOP

Introduction
Maize (*Zea mays* L.) is an important cereal crop which belongs to the grass family with chromosome number 2n = 20. It is the world's second most widely grown crop and India's third most important cereal crop after rice and wheat. It is cultivated as a cereal grain that has been domesticated in Central America. Globally, maize is known as the "Queen of cereal crops" because of its higher grain yield potential among all the cereals. It exhibits greater adaptability as it can be grown in a variety of agro-climatic conditions.
Potassium is the third major plant nutrient next to nitrogen and phosphorous with respect to crop production. The requirement for potassium in maize is high as it absorbs high quantities of potassium. It plays a significant role in enhancing crop quality, so it is recognized as a "quality element". It is associated with the movement of water, carbohydrates and nutrients in plants. About 80 different types of enzymes are stimulated by potassium (Kasana and Khan, 1976) [8].

It plays an important role in the stomatal functioning and helps plants to grow under drought conditions (Hsiao, 1973) [5]. Insufficient potassium in plants leads to difficulty in absorbing water, which leads to an increase in drought stress. Generally, maize plants conserve water and reduce moisture stress by closing leaf stomata, which in terms are regulated by potassium. That's why plants with inadequate potassium supply may be slower in closing their stomata, which reduces drought stress.

Zeolites are hydrated alumino silicate minerals made up of cross-linked tetrahedra of AlO_4 and SiO_4, which consist of pores and corners of alumino silicate tetrahedra (AlO_4 and SiO_4) that are connected in three-dimensional structure of about 12 Å in diameter, connected by channels of about 8 Å diameter and made up of rings of 12 linked tetrahedron (Kaduk and Faber, 1995) [7]. Zeolites with distinct cation exchange properties, molecular sieving and adsorption (Mumpton, 1999; Glisic *et al.*, 2009; Hecl and Toth, 2009) [13, 3, 4] could be used as a stabilizer, chelator and fertilizer (Loizidou and Kapetanios, 1992 and Perez-Caballero *et al.*, 2008) [12, 15]. Zeolites are excellent carriers and regulators of mineral fertilizers. Besides, they also serve as a source of nutrients. As carriers of N and K fertilizers, they can increase N and K use efficiency and decrease the application rates for equal yield to be achieved (Polat *et al.*, 2004) [17], zeolite enables both inorganic and organic fertilizers to slowly release their nutrients (Perez Caballero *et al.*, 2008) [15].

Materials and Methods

Layout and experimental design

The field experiment was conducted at PGI Research Farm, M.P.K.V., Rahuri. The soil sample was collected and analyzed at Department of Soil Science and Agricultural Chemistry, PGI, M.P.K.V., Rahuri, Dist. Ahmednagar during *summer* 2022. The experiment was laid out in a randomized block design with 10 treatments and 3 replications. The gross plot size was 4.50 m x 3.60 m i.e. 16.2 m^2 and net plot size was 3.0 m x 3.20 m i.e. 9.60 m^2. The recommended spacing of 75 cm x 20 cm was adopted for dibbling of maize. The general recommended dose of nutrients (120:60:40 kg ha^{-1} N, P_2O_5 and K_2O respectively + FYM @ 10 t ha^{-1}) were given to maize as per treatment details except T_1 at the time of dibbling of maize.

Soils characteristic: The topography of experimental site was nearly uniform. Plots are prepared for sowing of maize, soils are medium black with good water holding capacity. Initial soil properties of soil before sowing are presented in table 1.

Table 1: Initial soil properties of experimental site

Sr. No.	Parameters	Value
I	**Physical properties**	
1.	Bulk density (Mg m^{-3})	1.35
2.	Partical density (Mg m^{-3})	2.65
3.	Porosity (%)	49.06
4.	COLE value	0.50
5.	Hydraulic conductivity (cm h^{-1})	0.24
II	**Chemical properties**	
1.	pH (1:2.5)	8.18
2.	EC (1:2.5) (dSm^{-1})	0.23
3.	Organic carbon (%)	0.54
4.	Calcium carbonate (%)	6.75
5.	CEC (cmol (p^+) kg^{-1})	47.16
6.	Available N (kg ha^{-1})	218.6
7.	Available P (kg ha^{-1})	16.32
8.	Available K (kg ha^{-1})	425.6
9.	Available Fe (mg kg^{-1})	4.46
10.	Available Mn (mg kg^{-1})	9.14
11.	Available Zn (mg kg^{-1})	0.56
12.	Available Cu (mg kg^{-1})	1.94
13.	Available B (mg kg^{-1})	0.72

Zeolite

Highly fine powdered zeolite purchased from Rudra Zeochem Pvt. Ltd., Nashik on the name Agripower-A-Z is a potential enriched zeolite and it is characterized for different chemical properties by standard methods. The chemical properties of zeolite are given in table 2.

Table 2: Characterization of zeolite

Sr. No.	Parameter	Value
1.	pH (1:10)	6.62
2.	EC (1:10) (dSm^{-1})	0.09
3.	CEC (cmol (p^+) kg^{-1})	161

Application of Zeolite and Potassium

Zeolite and Potassium as per treatment with farm yard manure @ 10 t ha^{-1} to all treatment plots except T_1.

The treatment comprised of T_1: Absolute control, T_2: GRDF 120:60:40 N, P_2O_5, K_2O + 10 t FYM ha^{-1}, T_3: Zeolite @ 400 kg ha^{-1}, T_4: Zeolite @ 600 kg ha^{-1}, T_5: Zeolite @ 400 kg ha^{-1} + 50% K_2O of RDF (20 kg ha^{-1}), T_6: Zeolite @ 400 kg ha^{-1} + 75% K_2O of RDF (30 kg ha^{-1}), T_7: Zeolite @ 400 kg ha^{-1} + 100% K_2O of RDF (40 kg ha^{-1}), T_8: Zeolite @ 600 kg ha^{-1} + 50% K_2O of RDF (20 kg ha^{-1}), T_9: Zeolite @ 600 kg ha^{-1} + 75% K_2O of RDF (30 kg ha^{-1}), T_{10}: Zeolite @ 600 kg ha^{-1} + 100% K_2O of RDF (40 kg ha^{-1}).

Plant analysis

The plant samples were collected at harvest of maize. The samples were air dried in sunlight and then dried in oven at 70^0C till constant weight obtained. The whole plant sample of each treatment was grinded through a stainless steel willey mill after oven drying. Digestion of plant samples were done and used for estimation of nutrient concentration *viz.*, N, P, K and micronutrients Fe, Zn, Mn and Cu by using standard methods. Total N: Micro-Kjeldahl (Parkinson and Allen 1975) [14], Total P: Vanadomolybdate yellow colour method in nitric acid

(Jackson 1973) [6], Total K: Flame photometry (Chapman and Pratt, 1961) [2] and Total micronutrient (Fe, Mn, Zn and Cu) Atomic absorption Spectrophotometry (Zososki and Burau 1977) [20].

$$KUE\ (\%) = \frac{\text{Total K uptake at different treatment - Total K uptake at control treatment}}{\text{Potassium applied through fertilizer}} \times 100$$

Results and Discussion

Effect of different levels of zeolite and potassium application on total uptake of N, P and K by maize after harvest

The data regarding effect of different levels of zeolite and potassium application on total uptake of N, P and K uptake after harvest of maize are shown in table 3.

The uptake of nitrogen was significantly influenced by the application of different levels of zeolite and potassium after harvest of maize. Significantly, the highest N uptake (213.30 kg ha^{-1}) was observed in treatment T_{10} i.e., zeolite @ 600 kg ha^{-1} + 100% K_2O of RDF (40 kg ha^{-1} K_2O) over the rest of treatments except treatment T_9 (207.83 kg ha^{-1}) which was statistically at par where we have applied zeolite @ 600 kg ha^{-1} + 75% K_2O of RDF (30 kg ha^{-1} K_2O). Lija *et al.* (2014) [11] and Lathifa *et al.* (2011) [9] conducted experiments on maize with zeolite and they observed a positive relationship between nitrogen uptakes with zeolite application.

The uptake of phosphorous was significantly influenced by the application different levels of zeolite and potassium. Significantly, the highest (23.16 kg ha^{-1}) total phosphorous uptake was observed in the treatment T_{10} i.e., zeolite @ 600 kg ha^{-1} + 100% K_2O of RDF (40 kg ha^{-1} K_2O) over the rest of treatments except T_9 (22.20 kg ha^{-1}) which was statistically at par where we have applied zeolite @ 600 kg ha^{-1} + 75% K_2O of RDF (30 kg ha^{-1} K_2O). This might be because of the zeolite which, in combination with a single superphosphate act as an exchange fertilizer, where Ca^{2+} from the mono calcium phosphate exchanges onto the zeolite in response to plant uptake of nutrient cations like (NH_4^+ or K^+) which enhance the dissolution of the SSP as reported by (Ramesh *et al.*, 2011) [10].

The uptake of potassium was significantly influenced by the application of different levels of zeolite and potassium. Significantly, the highest potassium uptake (140.24 kg ha^{-1}) was observed in the treatment T_{10} (Zeolite @ 600 kg ha^{-1} + 100% K_2O of RDF (40 kg ha^{-1} K_2O) over the rest of the treatments except T_7 (138.16 kg ha^{-1}) which was found to be statistically at par where we have applied zeolite @ 400 kg ha^{-1} and 100% K_2O of RDF (40 kg ha^{-1} K_2O).

Table 3: Effect of different levels of zeolite and potassium application on total uptake of nitrogen, phosphorous and potassium after harvest of maize

Tr. No.	Treatment details	Total nutrient uptake (kg ha^{-1})		
		N	P	K
T_1	Absolute control	64.23	9.68	103.64
T_2	GRDF (120:60:40 N: P_2O_5: K_2O kg ha^{-1} +10 t ha^{-1} FYM	157.97	17.53	128.16
T_3	Zeolite @ 400 kg ha^{-1}	163.33	14.16	115.15
T_4	Zeolite @ 600 kg ha^{-1}	168.63	15.54	118.45
T_5	Zeolite @ 400 kg ha^{-1} + 50% K_2O of RDF (20 kg ha^{-1} K_2O)	170.70	18.83	123.82
T_6	Zeolite @ 400 kg ha^{-1} + 75% K_2O of RDF (30 kg ha^{-1} K_2O)	185.10	19.36	128.23
T_7	Zeolite @ 400 kg ha^{-1} + 100% K_2O of RDF (40 kg ha^{-1} K_2O)	193.00	20.92	138.16
T_8	Zeolite @ 600 kg ha^{-1} + 50% K_2O of RDF (20 kg ha^{-1} K_2O)	190.87	21.32	121.70
T_9	Zeolite @ 600 kg ha^{-1} + 75% K_2O of RDF (30 kg ha^{-1} K_2O)	207.83	22.20	130.51
T_{10}	Zeolite @ 600 kg ha^{-1} + 100% K_2O of RDF (40 kg ha^{-1} K_2O)	213.30	23.16	140.24
SE(m)±		2.433	0.507	0.808
CD at 5%		7.23	1.50	2.40

This increase in the total uptake of K by maize may be attributed to the sorption and release of added potassic fertilizer by zeolite, ascertaining its constant supply throughout the growth period of maize. Lija *et al.* (2014) [11] and Li *et al.* (2021) [10] both observed an increase in the uptake of potassium by application of potash along with zeolite.

Effect of different levels of zeolite and potassium application on total uptake of Fe, Mn, Zn and Cu by maize after harvest

The data regarding the effect of different levels of zeolite and potassium application on total uptake of Fe, Mn, Zn and Cu uptake after harvest of maize are shown in table 4.

Table 4: Effect of different levels of zeolite and potassium on total micronutrients (Fe, Mn, Cu, Zn) uptake in soil after harvest of maize

Tr. No.	Treatment details	Total micronutrient uptake (g ha^{-1})			
		Fe	Zn	Mn	Cu
T_1	Absolute control	1489.53	736.00	256.67	34.39
T_2	GRDF (120:60:40 N: P_2O_5: K_2O kg ha^{-1} +10 t ha^{-1} FYM	2125.07	1091.27	684.67	97.00
T_3	Zeolite @ 400 kg ha^{-1}	2288.80	955.40	573.43	77.13
T_4	Zeolite @ 600 kg ha^{-1}	2230.87	1078.60	625.53	88.00
T_5	Zeolite @ 400 kg ha^{-1} + 50% K_2O of RDF (20 kg ha^{-1} K_2O)	2343.07	1131.93	748.67	105.40
T_6	Zeolite @ 400 kg ha^{-1} + 75% K_2O of RDF (30 kg ha^{-1} K_2O)	2373.13	1141.20	774.67	115.53
T_7	Zeolite @ 400 kg ha^{-1} + 100% K_2O of RDF (40 kg ha^{-1} K_2O)	2450.73	1173.23	848.00	116.60
T_8	Zeolite @ 600 kg ha^{-1} + 50% K_2O of RDF (20 kg ha^{-1} K_2O)	2466.40	1182.07	883.80	124.93
T_9	Zeolite @ 600 kg ha^{-1} + 75% K_2O of RDF (30 kg ha^{-1} K_2O)	2515.00	1205.07	904.40	134.87
T_{10}	Zeolite @ 600 kg ha^{-1} + 100% K_2O of RDF (40 kg ha^{-1} K_2O)	2548.83	1210.53	913.27	141.87
	SE(m)±	18.58	7.270	5.69	2.441
	CD at 5%	55.20	21.60	16.92	7.25

The micronutrient uptake was significantly influenced by the application of different levels of zeolite and potassium after harvest of maize. Significantly, the highest total uptake of Fe, Mn, Zn and Cu (2548.23, 1210.53, 913.27 and 141.87 g ha^{-1} respectively) was observed in treatment T_{10} i.e., zeolite @ 600 kg ha^{-1} + 100% K_2O of RDF (40 kg ha^{-1} K_2O) over the rest of treatments except treatment T_9 (2515.00, 1205.53, 904.40 and 141.87 g ha^{-1} respectively) which was found to be statistically at par where we have applied zeolite @ 600 kg ha^{-1} + 75% K_2O of RDF (30 kg ha^{-1} K_2O).The significant increase in the uptake of micronutrients is because of their continuous supply by FYM and zeolite. An increase in the concentration of Fe, Mn, Zn and Cu in beet plants was observed with the application of zeolite as reported by Yamada *et al.* (2002) [19].

Effect of different levels of zeolite and potassium application on potassium use efficiency after harvest of maize

The data regarding the effect of different levels of zeolite and potassium application on potassium use efficiency of maize is presented in table 5. The potassium use efficiency was significantly influenced by the application of different levels of zeolite and potassium. Significantly, the highest potassium use efficiency (92.50%) was observed in treatment T_{10} i.e., zeolite @ 600 kg ha^{-1} + 100% K_2O of RDF (40 kg ha^{-1} K_2O) over the rest of treatments except treatment T_9 (91.66%) which was found to be statistically at par, where we have applied zeolite @ 600 kg ha^{-1} + 75% K_2O of RDF (30 kg ha^{-1} K_2O). However, the lowest potassium use efficiency (65.50%) was observed in the treatment T_2 GRDF i.e., 120:60:40 N: P_2O_5: K_2O kg ha^{-1} + 10 t ha^{-1} FYM without zeolite application. The results indicate that application of zeolite @ 600 kg ha^{-1} along with the recommended dose of fertilizer increased the potassium use efficiency by 65.50%. This indicated that treatments with different dosses of potassium along with zeolite application increased the potassium use efficiency.

The zeolites have good capability for effective K adsorption (Perumal *et al.*, 2021) [16], so the leaching loss of potassium will be decreased (Allen *et al.*, 1993) [1] and the top soil available K will be increased (Li *et al.*, 2021) [10]. So, plants will uptake more potassium eventually, the potassium use efficiency was increased when applied along with zeolite.

Table 5: Effect of levels of zeolite and potassium on potassium use efficiency after harvest of maize

Tr. No.	Treatment details	Potassium use efficiency (%)
T_1	Absolute control	-
T_2	GRDF (120:60:40 N:P_2O_5:K_2O kg ha^{-1} +10 t ha^{-1} FYM	65.50
T_3	Zeolite @ 400 kg ha^{-1}	-
T_4	Zeolite @ 600 kg ha^{-1}	-
T_5	Zeolite @ 400 kg ha^{-1} + 50% K_2O of RDF (20 kg ha^{-1} K_2O)	85.00
T_6	Zeolite @ 400 kg ha^{-1} + 75% K_2O of RDF (30 kg ha^{-1} K_2O)	86.64
T_7	Zeolite @ 400 kg ha^{-1} + 100% K_2O of RDF (40 kg ha^{-1} K_2O)	88.75
T_8	Zeolite @ 600 kg ha^{-1} + 50% K_2O of RDF (20 kg ha^{-1} K_2O)	90.00
T_9	Zeolite @ 600 kg ha^{-1} + 75% K_2O of RDF (30 kg ha^{-1} K_2O)	91.66
T_{10}	Zeolite @ 600 kg ha^{-1} + 100% K_2O of RDF (40 kg ha^{-1} K_2O)	92.50
	SE(m)±	0.392
	CD at 5%	1.17

Conclusion

Application of zeolite @ 600 kg ha^{-1} along with RDF (120:60:40 N: P_2O_5:K_2O kg ha^{-1} + 10 t ha^{-1} FYM) to hybrid maize found beneficial for increase in nutrient uptake, and potassium use efficiency in medium black soils (Inceptisol). However, the treatment T_9 zeolite @ 600 kg ha^{-1} along with fertilizer dose of 120: 60: 30 N: P_2O_5: K_2O + 10 t ha^{-1} of FYM found statistically at par and reduced by 25% dose of potassium to maize.

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