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Effect of zeolite application on physico-chemical properties of soil at grand growth stage and after harvest of preseasonal sugarcane grown on inceptisol

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Abstract
An investigation carried out to study the impact of zeolite on the chemical and physical characteristics of soil under pre-seasonal sugarcane cultivation. The treatment included of absolute control, GRDF (340:170:170 N:P_2O_5:K_2O + 20 t FYM ha^{-1}) as the, eight zeolite levels (300, 600, 900, 1200, 1800, 2100, and 2400 kg ha^{-1}) in addition to GRDF. Ten treatments and four duplicates were used in a randomized block design for the experiment. At the grand growth stage and following the harvest of preseasonal sugarcane, soil samples were taken at a depth of 0–20 cm in order to measure several soil parameters, including pH, electrical conductivity, organic carbon, calcium carbonate, cation exchange capacity, bulk density, and available water content. Zeolite was discovered to have a considerable impact on both pH and EC. When it came to organic carbon, the rise was 1.3 times more than the starting value of 0.58% throughout the grand growth stage and 1.2 times after the preseasonal sugarcane was harvested. In treatment T_{10} (GRDF + Zeolite @ 2400 kg ha^{-1}), the percentage of calcium carbonate content was found to be considerably higher during the grand growth stage (6.91%) and after harvest (6.80%). Application of zeolite was found to increase the soil's cation exchange capacity and accessible water content. However, the addition of zeolite caused the bulk density of the soil to decrease. Therefore, it was discovered that adding zeolite to the soil improved its physico-chemical qualities.

Keywords: Zeolite, sugarcane, CEC, soil properties, inceptisols

Introduction
Zeolites are hydrated aluminosilicate minerals composed of silica (SiO_4) and alumina (AlO_4) tetrahedra that are interconnected. In addition, they are solids made of silicon, oxygen, and aluminum that have a somewhat open, three-dimensional crystal structure. Water molecules are trapped in the spaces between the metals, which can be either alkali or alkaline (such as sodium, potassium, or magnesium). Zeolites have a wide variety of crystalline formations that form with big open pores (also called cavities) arranged in a very regular fashion and about the same size as tiny molecules.

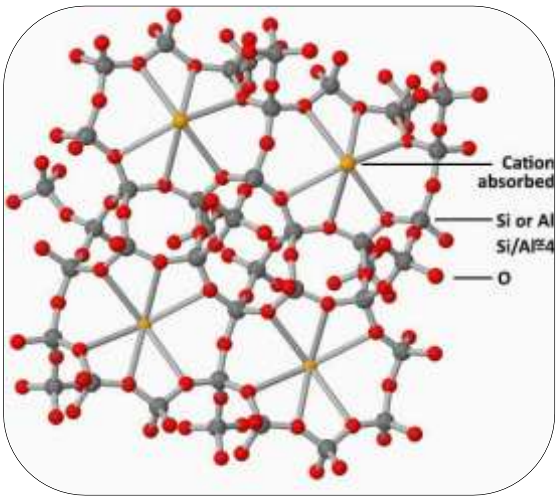

Fig 1: The tetrahedral framework of clinoptilolite zeolite

Zeolites are made up of three-dimensional frameworks connected by pores and corner-sharing aluminosilicate (AlO_4 and SiO_4) tetrahedrons. The pore structure is made up of cages with a diameter of about 12 Å that are connected by channels with a diameter of about 8 Å. These channels are made up of rings made up of 12 linked tetrahedrons (Kaduk and Faber, 1995) [8]. Depending on the material, the network of interconnected pores forms long, wide channels of different diameters. The resident ions and molecules can easily enter and exit the structure thanks to these channels. Zeolites resemble honeycomb or cage-like formations and include enormous empty areas or cages within.

Clinoptilolite is the naturally occurring zeolites that is most frequently employed in agriculture (Ramesh and Reddy, 2011) [14]. The physics, chemistry, and biology of soils are altered by zeolites, which have micropores with molecular dimensions of less than one nm. The micro images captured by a scanning electron microscope showed different types of zeolites to have tubular (Ramesh *et al.*, 2014) [15-16], cuboid (Ramesh *et al.*, 2014) [15-16], and amorphous foliated (Ramesh *et al.*, 2015) [17] crystals. Since they can act as both a carrier and a dispenser of plant nutrients, they are increasingly being studied in relation to a variety of agricultural challenges (Ramesh and Reddy, 2011) [14], of particular interest are their ion-exchange capabilities.

The main cash crop farmed in Maharashtra, India, is sugarcane. Sugarcane is a demanding crop that draws a lot of nutrients from the soil. If sufficient amounts of plant food nutrients are not applied, the crop yield and soil nutrients will decrease as a result of ongoing cultivation. Using fertilizers wisely offers one of the fastest ways to boost sugarcane yields. In order to increase yields per unit area, the most crucial resource is an appropriate supply of plant nutrients.

The three most significant macronutrients—nitrogen, phosphorus, and potash—as well as the micronutrients—iron, magnesium, zinc, and copper—must be supplied in balance to sugarcane, where quality standards have a major impact on sugar recovery. According to Valente *et al.* (1986) [22], zeolites have the ability to boost crop output in addition to acting as a soil conditioner and improving soil fertility. For this reason, their inclusion in fertilizer management for agriculture is crucial.

Both organic and inorganic fertilizers can release their nutrients gradually thanks to zeolites (Perez-Caballero *et al.*, 2008) [13]. Though zeolite will enhance soil qualities and nutrient availability, there is a lack of information regarding the appropriate dosage of zeolites to be utilized with, for example, organic and inorganic fertilizers. Thus, a study was conducted to see how applying zeolite affected the characteristics of the soil and the availability of nutrients.

Materials and Methods

The study was carried out in the preseasonal sugarcane of the STCRC Research Farm, Department of Soil Science and Agricultural Chemistry, Mahatma Phule Krishi Vidyapeeth, Rahuri, District Ahmednagar, in 2017–19 on Inceptisol soils. The fine montmorillonite hyperthermic family of Vertic Haplustepts includes Inceptisol, which is the soil type under which the experimental site's soils were classified. The medium deep black soil at the experimental site had a depth of 80 cm, was dominated by the clay mineral montmorillonite, and had a high swell-shrink property.

The Cattle Project, M.P.K.V., Rahuri provided well-decomposed farmyard manure, which was put to all treatment plots (except from the control) at a rate of 20 t ha^{-1} in accordance with recommendations. We bought extremely finely ground zeolite powder from Rudra Zeochem Pvt. Ltd. in Nashik. A potential enhanced zeolite was a product called Agripower-AZ. Standard analytical techniques were employed to characterize the various chemical characteristics of the zeolite powder that was acquired from Rudra Zeochem.

Nutrient dosage recommendations were (340:170:170 kg ha^{-1} N, P_2O_5, and K_2O). In accordance with the treatment plan, the necessary N was added as urea, P_2O_5 as single superphosphate, and K_2O as muriate of potash. Following a thorough mixing process, the fertilizer, farmyard manure, and zeolite were applied according to treatment. Ten treatments and four replications made up the randomized block design of the experiment (Table 1).

Each replication's soil samples were taken in order to evaluate the soil's characteristics and nutrient availability both throughout the grand growth stage and during the preseasonal sugarcane harvest. After shaking the soil sample intermittently for 20 to 30 minutes, the pH of the 1:2.5 soil water suspension was measured using a potentiometric pH meter (Elico CM 180) (Jackson, 1973) [7]. Using an EC meter and the conductometric (Elico CM 180) method, the total soluble salts (EC) in a 1:2.5 soil water solution were measured (Jackson, 1973) [7].

Wet digestion was used to measure the amount of organic carbon in 0.5 mm sieved soil (Walkley and Black, 1934) [23]. The clod method was used to calculate the bulk density of soil sample (Blake and Hartage, 1986) [3]. "Cation Switching The ammonium acetate method" was used to evaluate the capacity of soil samples (Page *et al.*, 1982) [12]. The pressure plate method (Richards, 1968) [19] was used to determine the available water content of soil samples. Rapid titration was used to assess the calcium carbonate content of the soil (Jackson, 1973) [7].

Table 1: Treatment Details

Sr. No.	Treatment
T_1	Absolute control
T_2	GRDF (340:170:170 N:P_2O_5:K_2O + 20 t FYM ha^{-1})
T_3	GRDF + Zeolite @ 300 kg ha^{-1}
T_4	GRDF + Zeolite @ 600 kg ha^{-1}
T_5	GRDF + Zeolite @ 900 kg ha^{-1}
T_6	GRDF + Zeolite @ 1200 kg ha^{-1}
T_7	GRDF + Zeolite @ 1500 kg ha^{-1}
T_8	GRDF + Zeolite @ 1800 kg ha^{-1}
T_9	GRDF + Zeolite @ 2100 kg ha^{-1}
T_{10}	GRDF + Zeolite @ 2400 kg ha^{-1}

Results and Discussion

a) pH

The table No. 2 displayed the results on soil pH in post-harvest soil samples at grand growth stage. The pH of the soil has been considerably raised by zeolite. The application of zeolite at a rate of 2400 kg ha^{-1} with GRDF resulted in the noticeably highest soil pH (8.48) at the grand growth stage. This was followed by soil pH (8.39 and 8.36) seen in the treatment with zeolite at a rate of 2100 kg ha^{-1} and 1800 kg ha^{-1} together with GRDF, respectively. Similarly, at the time of preseasonal sugarcane harvest, the treatment that applied 2400 kg ha^{-1} of zeolite with GRDF reported the highest soil pH (8.38). At the preseasonal sugarcane harvest (7.89) and grand growth stage (8.12), the treatment absolute control (T1) yielded the noticeably lowest soil pH readings.

Higher zeolite may have resulted from its ability to hold soil ammonium ions inside its pores, as evidenced by the higher pH value seen in the soil treated with zeolite at 2400 kg ha^{-1} together with GRDF. K+ or NH_4+ from the zeolite may be replaced by H^+ in solution. This procedure raised the pH of the solution. According to Nursanti and Kemala (2019) [11], zeolites have the ability to neutralize acid soils because to their pH 7.2 acidity and their ability to adsorb Al and Fe, which create soil acidity, while releasing alkaline cations like Ca, Mg, and K. On acidic soils, zeolites can raise the pH of the soil (Aainaa *et al.*, 2015; and Gaol *et al.*, 2014) [1, 5].

Table 2: Effect of zeolite on pH and electrical conductivity in preseasonal sugarcane grown on Inceptisol

Tr. No.	Treatment	Soil properties			
		pH (1:2.5)		EC (dS m^{-1})	
		Grand growth stage	After harvest	Grand growth stage	After harvest
T_1	Absolute control	8.12	7.89	0.36	0.23
T_2	GRDF (340:170:170 kg ha^{-1} $N:P_2O_5:K_2O$ + 20 t FYM ha^{-1})	8.14	7.99	0.42	0.27
T_3	GRDF + Zeolite @ 300 kg ha^{-1}	8.20	7.92	0.43	0.28
T_4	GRDF + Zeolite @ 600 kg ha^{-1}	8.23	7.99	0.45	0.28
T_5	GRDF + Zeolite @ 900 kg ha^{-1}	8.27	8.09	0.51	0.30
T_6	GRDF + Zeolite @ 1200 kg ha^{-1}	8.28	8.24	0.51	0.31
T_7	GRDF + Zeolite @ 1500 kg ha^{-1}	8.30	8.29	0.52	0.31
T_8	GRDF + Zeolite @ 1800 kg ha^{-1}	8.36	8.34	0.52	0.32
T_9	GRDF + Zeolite @ 2100 kg ha^{-1}	8.39	8.36	0.54	0.32
T_{10}	GRDF + Zeolite @ 2400 kg ha^{-1}	8.48	8.38	0.58	0.33
SEm±		0.06	0.10	0.03	0.02
CD at 5%		0.17	0.29	0.07	0.05
Initial		8.16		0.24	

b) Electrical conductivity

Analysis of the collected data reveals that zeolite considerably raised the soil's electrical conductivity (Table 2). When 2400 kg ha^{-1} of zeolite was applied in conjunction with GRDF during the grand growth stage (0.58 dS m^{-1}) and after harvest (0.33 dS m^{-1}) of preseasonal sugarcane, the soil's electrical conductivity was much higher. Conversely, the absolute control treatment produced the lowest values (0.36 dS m^{-1}) during the grand growth stage and (0.23 dS m^{-1}) following harvest. However, zeolites add cations to the water used to test the EC, their high exchange capacity increases electrical conductivity. According to Al-Busaidi *et al.* (2008) [2], the zeolite's ability to store salt and the presence of minerals are what cause the rise in soil electrical conductivity in the zeolite treatments. According to research by Ravali *et al.* (2020), zeolite greatly enhanced the electrical conductivity of soil.

c) Organic carbon

According to data, the amount of organic carbon in the soil increased steadily when zeolite and GRDF were applied conjointly (Table 3). Nonetheless, the increase's magnitude was 1.3 times more than the starting value of 0.58% during the grand growth stage and 1.2 times following the preseasonal sugarcane harvest. When zeolite was applied at 2400 kg ha^{-1} in conjunction with GRDF, the organic carbon content was considerably higher (0.78%) at the grand growth stage. This result was found to be statistically comparable to when zeolite was applied at 1200, 1500, 1800, and 2100 kg ha^{-1} in conjunction with GRDF (0.73, 0.74, 0.74, and 0.76%, respectively). But when zeolite was applied at a rate of 2400 kg ha^{-1} in conjunction with GRDF, a greater organic carbon content (0.72%) was seen after harvest. This was followed by zeolite at a rate of 1200, 1500, 1800, and 2100 (0.68, 0.68, 0.69, and 0.69 respectively). Conversely, at both stages of preseasonal sugarcane, the control treatment showed the lowest soil organic carbon concentration (0.68 and 0.62%).

The addition of FYM and increased root biomass from the zeolite application, which increased soil accessible phosphorus, may be the cause of the soil's increased organic carbon content. Chalwade *et al.* (2006) [4] found that applying both organic and inorganic sources of phosphorus increased the amount of organic carbon, which may have resulted from an increase in the number of microfauna.

Table 3: Effect of zeolite on organic carbon and calcium carbonate in preseasonal sugarcane grown on Inceptisol

Tr. No.	Treatment	Soil properties			
		Organic carbon (%)		$CaCO_3$ (%)	
		Grand growth stage	After harvest	Grand growth stage	After harvest
T_1	Absolute control	0.68	0.62	5.90	5.80
T_2	GRDF (340:170:170 kg ha^{-1} $N:P_2O_5:K_2O$ + 20 t FYM ha^{-1})	0.70	0.65	6.10	5.90
T_3	GRDF + Zeolite @ 300 kg ha^{-1}	0.70	0.65	6.30	6.10
T_4	GRDF + Zeolite @ 600 kg ha^{-1}	0.71	0.67	6.38	6.14
T_5	GRDF + Zeolite @ 900 kg ha^{-1}	0.72	0.67	6.42	6.31
T_6	GRDF + Zeolite @ 1200 kg ha^{-1}	0.73	0.68	6.49	6.40
T_7	GRDF + Zeolite @ 1500 kg ha^{-1}	0.74	0.68	6.53	6.50
T_8	GRDF + Zeolite @ 1800 kg ha^{-1}	0.74	0.69	6.60	6.70
T_9	GRDF + Zeolite @ 2100 kg ha^{-1}	0.76	0.69	6.70	6.70
T_{10}	GRDF + Zeolite @ 2400 kg ha^{-1}	0.78	0.72	6.91	6.80
SEm±		0.02	0.01	0.18	0.22
CD at 5%		0.05	0.04	0.51	0.65
Initial		0.58		6.2	

d) Calcium carbonate

An increase in zeolite levels had a substantial impact on the soil's calcium carbonate concentration during the grand growth stage and following the harvest of preseasonal sugarcane (Table 3). Compared to the control and other treatments, treatment T_{10} (GRDF + Zeolite @ 2400 kg ha^{-1}) showed a considerably higher percentage of calcium carbonate content (6.91%) and after harvest (6.80%). At both stages, the control treatment yielded the lowest values (5.90 and 5.80%), respectively. The possible cause of the rise in calcium carbonate content could be the adsorption of calcium from monocalcium phosphate in soil solution, followed by its release during the crop's growth phase, which precipitated as calcium carbonate. Similar results were observed by Susana *et al.* (2015) [21], Kalhapure (2019) [9] and Sonawane (2019) [20].

e) Cation exchange capacity

According to the findings, zeolite considerably raised the soil's CEC from the beginning. At the grand growth stage and following the harvest of preseasonal sugarcane, the soil's capacity for cation exchange was measured (Table 4;). The treatment that applied zeolite @ 2400 kg ha^{-1} along with GRDF (T_{10}) at the grand growth stage of preseasonal sugarcane had the significantly highest soil cation exchange capacity [73.17 cmol (p+) kg^{-1}]. This treatment was statistically comparable to the other treatments (zeolite @ 600, 900, 1200, 1500, 1800, and 2100 kg ha^{-1} along with GRDF; CEC were 64.37, 65.34, 68.39, 72.12, 71.38, and 72.34 cmol (p+) kg^{-1}), with the exception of the absolute control (T_1) GRDF (T_2) and zeolite @ 300 kg ha^{-1} along with GRDF (T_3).

In a similar vein, the treatment that applied zeolite @ 2400 kg ha^{-1} coupled with GRDF (T_{10}) at the time of preseasonal sugarcane harvest showed the significantly largest soil cation exchange capacity [72.80 cmol (p+) kg^{-1}]. The CEC values were 63.94, 63.94, 64.24, 67.48, 69.22, and 71.24 cmol (p+) kg^{-1}, respectively, for all treatments (zeolite @ 600, 900, 1200, 1500, 1800, and 2100 kg ha^{-1} along with GRDF), with the exception of the absolute control (T_1) GRDF (T_2) and zeolite @ 300 kg ha^{-1} along with GRDF (T3) following the harvest of preseasonal sugarcane.

Table 4: Effect of zeolite on cation exchange capacity and available water content in preseasonal sugarcane grown on Inceptisol

Tr. No.	Treatment	Soil properties			
		CEC [cmol(p^+) kg^{-1}]		AWC (%)	
		Grand growth stage	After harvest	Grand growth stage	After harvest
T_1	Absolute control	56.82	54.82	22.10	22.02
T_2	GRDF (340:170:170 kg ha^{-1} N:P_2O_5:K_2O + 20 t FYM ha^{-1})	62.28	61.12	22.13	22.12
T_3	GRDF + Zeolite @ 300 kg ha^{-1}	63.44	62.52	22.24	22.22
T_4	GRDF + Zeolite @ 600 kg ha^{-1}	64.37	63.10	22.29	22.27
T_5	GRDF + Zeolite @ 900 kg ha^{-1}	65.34	63.94	22.30	22.29
T_6	GRDF + Zeolite @ 1200 kg ha^{-1}	68.39	64.24	22.34	22.32
T_7	GRDF + Zeolite @ 1500 kg ha^{-1}	72.12	67.48	22.36	22.37
T_8	GRDF + Zeolite @ 1800 kg ha^{-1}	71.38	69.22	22.38	22.38
T_9	GRDF + Zeolite @ 2100 kg ha^{-1}	72.34	71.24	23.04	23.01
T_{10}	GRDF + Zeolite @ 2400 kg ha^{-1}	73.17	72.80	23.15	23.10
SEm±		3.32	3.46	0.27	0.24
CD at 5%		9.69	10.09	0.79	0.71
Initial		56		22.00	

The application of zeolite, which has a high CEC (cmol (p+) kg^{-1}), may be the cause of the rise in the CEC of the soil. The high CEC of zeolite was caused by the natural permanent negative charge on the surface of the honeycomb structure (Kedziora *et al.*, 2014) [10]. As a result of the high CEC of zeolite, the CEC of soil increased as zeolite levels increased.

f) Available water content

At the grand growth stage and after harvest, there was a consistent upward trend in the available water content compared to the initial 22.00 percent (Table 5). At the grand growth stage of preseasonal sugarcane, the treatment of zeolite at a rate of 2400 kg ha^{-1} in conjunction with GRDF resulted in a significantly higher available water content (23.15%). Nevertheless, in the grand growth stage, the soil available water content, as determined by applying 2100 kg ha^{-1} of zeolite in conjunction with GRDF (T_9), was shown to be statistically equal to 23.04 percent.

Following the harvest of preseasonal sugarcane, the treatment of zeolite at a rate of 2400 kg ha^{-1} combined with GRDF resulted in the greatest available water content (23.10%). After preseasonal sugarcane was harvested, treatment with GRDF + zeolite @ 2100 kg ha^{-1} statistically reported at par (23.01%) for available water content. Growing zeolite levels raised the available water content of the soil, which may have been caused by the zeolite's increased pore space and the soil's lower bulk density. Zeolites' high porosity crystalline structure allows them to retain up to 60% of their weight in water, as shown by studies by Ramesh and Reddy (2011) [14].

g) Bulk density

The bulk density of the soil was evaluated at the grand growth stage and was greatly impacted after harvest by the different zeolite levels and GRDF applied to preseasonal sugarcane (Table 4). In comparison to the starting bulk density of 1.35 Mg m^{-3} and all other treatments, the application of zeolite @ 2400 kg ha^{-1} in conjunction with GRDF recorded considerably lower bulk densities at the grand growth stage (1.26 Mg m^{-3}) and after harvest (1.29 Mg m^{-3}) of preseasonal sugarcane. On the other hand, the absolute control treatment had the highest bulk density (1.35 Mg m^{-3}) and in the grand growth stage (1.34 Mg m^{-3}).

The application of zeolite to the soil may have caused the drop in bulk density because of its crystalline structure, which enhances porosity and decreases bulk density. The decrease in bulk density could be caused by the increasing rate at which zeolite is applied. This could affect the physical characteristics of the soil, specifically total porosity, which would lower bulk density values. The outcomes aligned with the research conducted by Hassan and Mahmoud (2013) [6]. According to Xiliang *et al.* (1991) [24], applying zeolite encouraged the development of soil aggregates, which raised the porosity and lowered the bulk density of the soil.

Table 5: Effect of zeolite on bulk density in preseasonal sugarcane grown on Inceptisol

Tr. No.	Treatment	Soil properties	
		Bulk density (Mg m^{-3})	
		Grand growth stage	After harvest
T_1	Absolute control	1.34	1.35
T_2	GRDF (340:170:170 kg ha^{-1} $N:P_2O_5:K_2O$ + 20 t FYM ha^{-1})	1.32	1.33
T_3	GRDF + Zeolite @ 300 kg ha^{-1}	1.32	1.32
T_4	GRDF + Zeolite @ 600 kg ha^{-1}	1.31	1.32
T_5	GRDF + Zeolite @ 900 kg ha^{-1}	1.31	1.32
T_6	GRDF + Zeolite @ 1200 kg ha^{-1}	1.31	1.33
T_7	GRDF + Zeolite @ 1500 kg ha^{-1}	1.29	1.33
T_8	GRDF + Zeolite @ 1800 kg ha^{-1}	1.28	1.32
T_9	GRDF + Zeolite @ 2100 kg ha^{-1}	1.28	1.29
T_{10}	GRDF + Zeolite @ 2400 kg ha^{-1}	1.26	1.29
SEm±		0.02	0.01
CD at 5%		0.05	0.03
Initial		1.35	

Conclusion

It has been found that adding zeolite to soil can improve its physico-chemical characteristics. In order to increase the availability of nutrients for the crop, zeolite and GRDF (340:170:170 kg ha^{-1} $N:P_2O_5:K_2O$ + FYM @ 20 t ha^{-1}) applied together greatly improved the soil reaction (pH), electrical conductivity (EC), organic carbon, calcium carbonate, cation exchange capacity (CEC), available water content, and bulk density.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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