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Effect of Zeolites on Soil Quality, Plant Growth and Nutrient Uptake Efficiency in Sweet Potato (*Ipomoea batatas* L.)

V. Ramesh[1], James George[2], Jissy S. Jyothi[3] and S.M.A. Shibli[4]

[1] ICAR-Central Tuber Crops Research Institute, Sreekariyam, Thiruvananthapuram 695 017, Kerala, India

[2] All India Coordinated Research Project on Tuber Crops, ICAR-Central Tuber Crops Research Institute, CTCRI, Sreekariyam, Thiruvananthapuram 695 017, Kerala, India

[3&4] Kerala University, Kariavattom, Thiruvananthapuram 695 581, Kerala, India

Corresponding author: V. Ramesh, e-mail: varadharajan_ramesh@rediffmail.com

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Abstract

Zeolites (sodium alumino silicates) are effective controlled nutrient release materials that are highly useful to improve plant uptake of nutrients especially NPK. Synthetic zeolites viz. fly ash based near neutral agricultural grade (FAZ) and commercial (CZ) zeolites (zeolite 4A) in different combinations were studied under pot culture for their effectiveness on NPK uptake. The experiment was conducted in completely randomized design (CRD) with six treatments viz. FAZ applied at 1% and 2% levels (w/w, zeolite: soil) (denoted as F1 and F2), pH treated CZ at 1% level, potassium and zinc impregnated CZ (KCZ and ZnCZ) at 1% level and a control (without zeolite). The treatments were replicated three times. Study showed that 1% zeolite amended soils registered a better soil moisture increase over control to an extent of 20.9 % and tuber yield increase of 57% over control. Soils amended with both FAZ levels are well below the critical limits in terms of SAR. The uptake efficiency of FAZ amended at 1% (F1) rate was significantly superior in respect of N and P as compared to F2 and control. The study also suggested that FAZ at 1% will be beneficial for sweet potato crop.

Key words: Fly ash zeolite, acid soil, soil moisture, chemical properties, nutrient uptake, sweet potato

Introduction

Excessive application of straight fertilizers resulted in low biological activity, deterioration of soil quality, poor moisture holding capacity and severe imbalance of plant nutrients that led to poor use efficiency of applied fertilizers/ nutrients in all types of soil (Ge et al., 2010; Loks et al., 2014). Low soil fertility is the single most pervasive constraint to high and sustainable production worldwide. Recently, conversion of fly ash to zeolites and its application to low quality soil is emerging as the promising technique to improve the use efficiency of nutrients (Amrhein et al., 1996). Zeolites are crystalline aluminum-silicates with group I and II elements as counter ions and are stable in soil environments. Their structure is made up of a frame work of $(SiO_4)^{4-}$ and $(AlO_4)^{5-}$ tetrahedral linked to each other at the corners by sharing their oxygens. They are excellent carriers, stabilizers and regulators of mineral fertilizers, besides themselves being source of certain nutrients. As a carrier of N and K fertilizers, zeolites increase N and K efficiency by decreasing application rates for equal yields to be achieved (Polat et al., 2004). Zeolites, natural or synthetic such as fly ash based zeolites (FAZ) or zeolite 4A (CZ), considerably raises the cation exchange capacity (CEC) of soils (Hershey et al., 1980) thus making it suitable for agricultural/horticultural crops and has huge potential in soil water and nutrient retention. However, FAZ for agricultural soil applications will be beneficial and have fertilizer value only if it possesses the following three characteristics *viz*. low sodium content with near neutral pH, high cation exchange capacity (CEC), minimum heavy metal content and maximum surface area for effective adsorption and retention of major cations of plant nutrient value.

Sweet potato is widely grown in eroded, marginally fertile, low quality soils in India. It is cultivated in 0.105 million ha with the production of 1.09 million tonnes in 2013-2014 (National Horticulture Board, 2015). Past research (Sugianto, 2005) on the effect of zeolites on soil nutrient efficiency in sweet potato focused only natural forms of zeolites. This paper reports the effect of synthetic zeolites viz. FAZ especially of agricultural grade applications on soil quality, nutrient use efficiency, growth and yield of sweet potato.

Materials and Methods

Bulk zeolite mixture of agricultural grade quality suitable for soil application (low sodium, near neutral pH, high CEC) was synthesized by hydrothermal method using fly ash and alkali mixtures. Fresh unweathered fly ash was collected from ash collection point of Tuticorin Thermal Power Station, Tamil Nadu, India and the acid pre-treated ash was mixed with NaOH and KOH, 1 M each and the following set of conditions was followed for the synthesis of FAZ. Solid/liquid ratio - 1:10, temperature - 121 ^oC, pressure - 15 psi and Time - 48 hours. Zeolite 4A (referred as commercial zeolite, CZ) was purchased from M/s. Henkel Spic, Karaikaal, Tamil Nadu, India. Both the zeolites were treated with acetic acid by neutralisation principle to bring down the pH to near neutral reaction. KCZ and ZnCZ were prepared from the treated CZ by ion exchange. For this, the CZ was stirred in 0.5 M KNO_3 and 0.05 M $ZnSO_4$ solutions for 6 hours with the ratio between the mass of zeolite to the volume of above solutions set at 1:5 for obtaining KCZ and ZnCZ respectively. The zeolite was filtered without washing and dried at 105^{o}C for 12 hours.

The physico-chemical characteristics of soil, FAZ and CZ were presented in Table 1.

The synthesized and pH treated FAZ and CZ's of above types were evaluated for their effects on soil properties and crop growth, yield of sweet potato, in a pot experiment conducted during 2013 at the research farm of ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, India. . The experiment was conducted in completely randomized design (CRD) with six treatment combinations viz. Control (soil alone, coded C), fly ash zeolites (1%, F1), fly ash zeolites (2%, F2), commercial zeolite 4A 1% (CZ), potassium impregnated in 1% commercial zeolite 4A (KCZ) and zinc impregnated in 1% commercial zeolite (ZnCZ). Each treatment was replicated three times.

Table 1. Initial characteristics of soil, fly ash zeolite and commercial zeolite used in the study

Parameter	Soil	FAZ	CZ
pH (1:2 soil: water, w/v)	5.15	6.68	7.96
CEC (cmol kg^{-1})	11.9	254.1	408.5
Na (g kg^{-1})	-	27.2	98.6
Texture	Sandy loam	Silt	Silty loam
Bulk density (Mg m^{-3})	1.67	1.01	nd
WHC (%)	37.1	48.7	nd

nd- not determined, FAZ-Fly Ash Zeolites, CZ-Commercial Zeolite (zeolite 4A), WHC-maximum water holding capacity

Air dried soil (2 mm sieved) of 15 kg was taken in a free-draining cement pots (measuring 36 cm top internal diameter and 28 cm depth) and thoroughly mixed with zeolites in conjunction with farm yard manure (5%) and phosphorus (156 mg P). The pots were maintained in a moist condition for a week in order to allow the soil mixture to stabilize. Fertilizer nutrients of 340.9 mg of N and 326.9 mg of K were applied per pot in two splits viz. before 3 days of crop planting and one month after first application. Vine cuttings of sweet potato variety ST-14 was planted at the rate of one per pot. Initial soil samples (one week after planting) and final soil samples (after harvest of sweet potato tubers) were collected and analyzed for pH, EC, CEC, exchangeable sodium, potassium using standard procedures. In addition, the volumetric soil water content of treatments were measured at seven stages using surface soil moisture theta probe (model ML2x; U.K) at 5, 15, 30, 45, 60 and 75 days after planting of crop.

Soil samples were taken at four different stages for estimation of available sodium and potassium contents to study the changes in nutrient availability with time. The sodium adsorption ratio (SAR) was calculated as follows: $SAR = Na^+/((Ca^{2+} + Mg^{2+})/2)^{1/2}$ where SAR is expressed in cmol kg^{-1} and Na^+, Ca^{2+}, Mg^{2+} is the measured exchangeable cations in cmol kg^{-1} (Seilsepour and Rashidi, 2011). Biometric observations viz. leaf number, number of branches and vine length of plants were taken at four different stages of crop growth. The total dry matter yield was estimated at harvest stage by summing up the leaf, stem, root and tuber portions and the NPK nutrient uptake was calculated individually for the above plant parts using the relationship of plant nutrient concentration and biomass which are then summed up to arrive at the total nutrient uptake. The nitrogen, phosphorus and potassium uptake efficiency (as a measure of nutrient use) of different treatments was calculated in per cent as the ratio of total nutrient uptake and total nutrients applied.

The effects of treatments were examined by employing ANOVA using statistics software SAS (Ver. 9.3; SAS Institute, USA). When significant differences were detected ($P < 0.05$), the Duncan's Multiple Range Test was applied to compare treatments ($P \leq 0.05$).

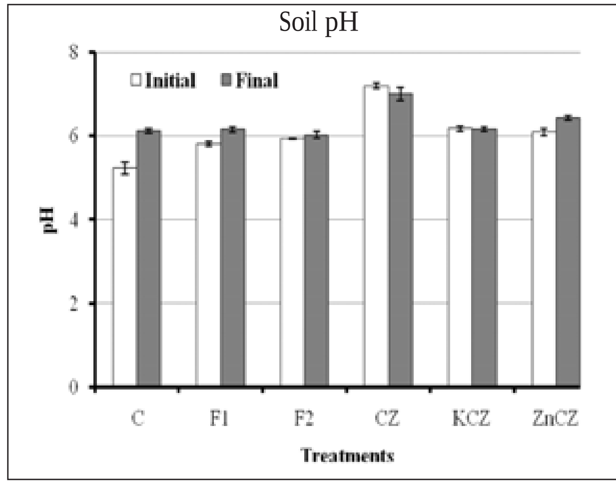
Results and Discussion

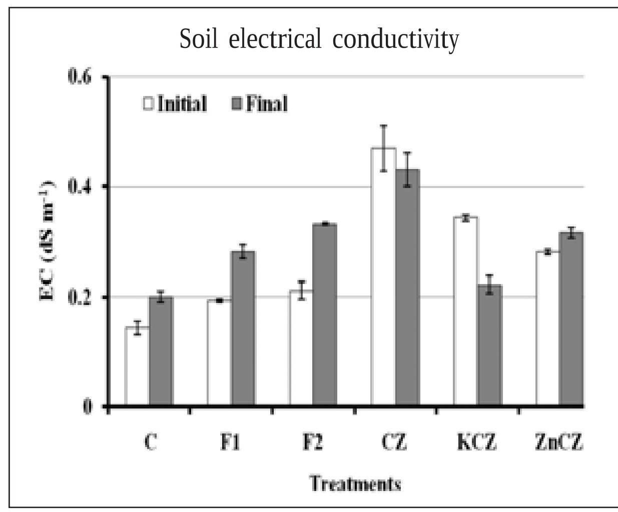
Soil pH and EC

Application of FAZ at both initial and final levels significantly increased the soil pH as compared to control (Fig. 1). However, there was no significant difference in pH values among two FAZ levels and also among the two impregnated zeolites. The near neutral pH of zeolite suggests its intermediate ability to exchange its Na^+ or K^+ with H^+ from the water since the CEC of FAZ and CZ were 254.1 and 408.5 cmol kg^{-1} respectively. Among the treatments, control and commercial zeolite 4A (CZ) was found to have the minimum (0.17 dSm^{-1}) and maximum values (0.45 dSm^{-1}) of electrical conductivity (EC). Addition of FAZ at 1 % and 2 % increased the EC by 38 and 56 % respectively. However, the values are well below the safe limits (4 dSm^{-1}). The high exchange capacity of zeolites contributes to the electrical conductivity because the zeolites can introduce cations to the water being used to measure the EC (Fansuri et al., 2008).

Soil moisture content

The soil moisture content among 30 and 45 DAP and also 75 and 90 DAP were at par with each other (Table 2). Regarding the treatment effects, the mean moisture for control soils recorded a value of 15.8 % while CZ treated soils had a moisture content of 24.1 %. There was no significant difference among F1 and F2 in influencing the soil moisture (19.1 % and 18.9 % respectively). Commercial zeolite had a greater benefit in respect of soil moisture content when applied at 1 %. In this study, fly ash zeolites increased the water content to 20.9 % as compared to control soil. Other researchers have also reported that soil water content in zeolite amended soils to be greater as compared to control soils because of the raw material fly ash, which alter soil texture, increase micro porosity and improve water holding capacity (Ghodrati et al., 1995; Page et al., 1979).





N.B: Error bar indicates standard deviation of mean values

Fig. 1. Variations in soil pH and EC values as influenced by different zeolite amendments

Exchangeable sodium, potassium and Sodium Adsorption Ratio (SAR)

In order to understand the K and Na adsorption efficiency of zeolites in comparison with control, soil samples were drawn at four different stages of crop growth and available (exchangeable) K and Na contents were determined. The

Table 2. Changes in soil moisture content (%, v/v) over stages as influenced by different zeolite treatments

Treatments	Days after planting (DAP)							
	5	15	30	45	60	75	90	Mean
C	22.6	16.5	11.9	11.4	15.6	15.4	17.2	15.8[e]
F1	27.9	20.1	13.2	13.9	16.8	21.6	20.6	19.1[d]
F2	24.2	23.0	15.3	13.3	16.9	19.0	20.9	18.9[d]
CZ	28.5	25.6	20.4	23.4	22.3	24.6	23.9	24.1[a]
KCZ	31.1	21.7	14.8	13.4	22.3	18.3	17.5	19.9[c]
ZnCZ	32.2	28.5	19.8	23.1	21.1	20.6	18.6	23.4[b]
Mean	27.8 [a]	22.6 [b]	15.9 [e]	16.4 [e]	19.2 [d]	19.9 [c]	19.7 [cd]	

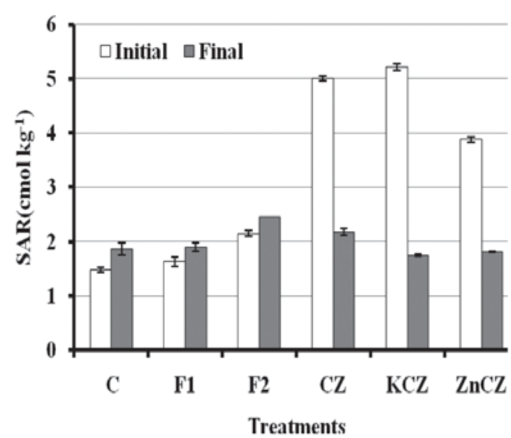
Note: Means followed by the same letter are not significantly different (P = 0.05)

mean exchangeable K contents of the four stages were 11.6, 11.1, 10.9 and 9.1 mmol kg^{-1} soil at 7, 30, 60 and 90 DAP respectively. There was no significant difference in the content of exchangeable K during first and second as well as second and third stage of samplings. Among the treatments, control registered lowest content (3.8 mmol kg^{-1}) while F2 amended soils had highest content of exchangeable K (26.9 mmol kg^{-1}). F1 and F2 varied significantly in the contents of exchangeable K (Table 3).

The available sodium contents were 30.4, 47.7, 31.6 and 27.6 mmol kg^{-1} for the soils collected during 7, 30, 60 and 90 DAP respectively and were significantly different from each other. Among the treatments, control and CZ had the lowest and highest content of sodium (20.8 and 54.4 mmol kg^{-1}) respectively. It could be observed that soils of F1 had 36% more Na as compared to control. The sodium content of impregnated zeolites (KCZ, ZnCZ) was greatly reduced as compared to CZ which indicated the extent of exchange of Na for that of K and Zn in the impregnated products. Likewise the SAR had a mean value of 2.61 cmol kg^{-1} and was far less than the threshold value of 12 cmol kg^{-1}. The SAR decreased at the final stage (1.99 cmol kg^{-1}) as compared to initial stage (3.22 cmol kg^{-1}). Among the treatments, control soils were found to have lowest SAR value (1.67 cmol kg^{-1}) whereas CZ was having 3.6 cmol kg^{-1} (Fig. 2). Overall, CZ treated soils had higher SAR values as compared to C, F1 and F2 during the initial stages which later decreased with time for all treatments.

Growth

A gradual increase in leaf number was observed in successive stages and the average values were 7.7, 57.5, 115.8 and 163.5 during 5, 30, 60 and 90 days after



N.B: Error bar indicates standard deviation of mean values

Fig. 2. Influence of different zeolite treatments on SAR values

Table 3. Soil exchangeable K and Na contents (mmol kg^{-1}) at different stages of crop due to different treatments

Treatments	Exch. K (mmol kg^{-1}) Days after planting (DAP)					Exch. Na (mmol kg^{-1}) Days after planting (DAP)				
	7	30	60	90	Mean	7	30	60	90	Mean
C	4.2 [d]	4.1 [d]	4.1 [e]	2.9 [d]	3.8 [e]	13.2 [f]	27.7 [e]	22.4 [c]	19.8 [f]	20.8 [f]
F1	16.9 [b]	10.3 [b]	12.2 [b]	12.5 [b]	12.9[b]	16.9 [e]	37.6 [d]	31.4 [b]	27.4 [d]	28.3 [e]
F2	28.7 [a]	26.3 [a]	31.2 [a]	21.3 [a]	26.9[a]	22.7 [d]	44.4 [c]	34.6 [b]	33.6 [a]	33.8 [c]
CZ	4.7 [d]	7.6 [c]	8.0 [c]	6.6 [c]	6.7 [d]	51.5 [a]	89.0 [a]	47.6 [a]	29.7 [c]	54.4 [a]
KCZ	10.2 [c]	10.7 [b]	4.1 [e]	5.3 [cd]	7.5 [c]	46.7 [b]	50.7 [b]	24.1 [c]	23.6 [e]	36.3 [b]
ZnCZ	4.9 [d]	7.4 [c]	6.0 [d]	6.2 [c]	6.1 [d]	31.6 [c]	36.7 [d]	29.7 [b]	31.6 [b]	32.4 [d]

Note: Means followed by the same letter are not significantly different (P = 0.05)

Table 4. Effect of zeolites on the growth of sweet potato

Treatments	Number of leaves				Number of branches				Vine length (cm)			
	5	30	60	90	5	30	60	90	5	30	60	90
C	8.0	51.7^{d}	113.3^{bc}	136.7^{c}	6.3^{ab}	4.7^{ab}	9.7^{cd}	10.7^{c}	42.3^{ab}	62.7^{b}	94.5^{a}	99.0
F1	7.7	65.3^{b}	145.3^{a}	212.7^{a}	6.3^{ab}	6.0^{ab}	11.7^{bc}	17.7^{b}	41.8^{ab}	66.3^{b}	81.2^{a}	86.5
F2	7.3	83.7^{a}	125.3^{ab}	194.3^{ab}	4.0^{c}	6.3^{ab}	15.0^{a}	21.0^{a}	47.5^{a}	78.0^{a}	89.7^{a}	92.0
CZ	8.0	26.3^{e}	92.0^{d}	107.0^{d}	8.0^{a}	1.7^{c}	7.3^{d}	9.3^{c}	23.8^{d}	48.7^{c}	86.7^{a}	88.8
KCZ	7.0	63.7^{bc}	117.7^{bc}	176.7^{b}	5.0^{bc}	6.7^{a}	12.3^{b}	18.7^{ab}	30.8^{c}	63.7^{b}	56.3^{b}	73.3
ZnCZ	8.0	54.3^{cd}	101.7^{cd}	153.7^{c}	6.3^{ab}	4.3^{b}	13.0^{ab}	17.0^{b}	36.7^{b}	63.7^{b}	72.8^{ab}	85.0
CD (0.05)	NS	9.7	20.0	20.1	1.7	2.0	2.4	3.0	5.6	8.1	23.4	NS

Note: Means followed by the same letter are not significantly different (P = 0.05)

planting and all were statistically significant (Table 4). Among the treatments, plant number under CZ was recorded lowest (58.3) where as F1 and F2 were having highest leaf number (107.8). The leaf number of control plants was found to be slightly higher than CZ.

A gradual increase in the number of branches were observed in successive growth stages and the average values were 4.9, 6, 11.5 and 15.7 at 5, 30, 60 and 90 days after planting and all were statistically significant. Among the treatments, average number of branches varied from 6.6 in case of CZ to 11.6 in F2. F1 (10.4) and ZnCZ (10.2) were at par with each other and higher in number than control (7.8). Thus F1 and F2 are significantly different in branches as well as vine length though they are at par in leaf number.

Among the stages, the vine length was 37.2, 63.8, 80.2 and 87.4 cm at 5, 30, 60 and 90 days after planting respectively and all were statistically significant. Among the treatments, control and KCZ recorded lowest vine length while the highest was recorded under F2.

Yield, tissue nutrient concentrations of NPK and nutrient uptake

The beneficial effect of F1 on tuber yield and total plant biomass of sweet potato was evident as compared to F2 and other treatments (Table 5). Though the yield of F2 was less than F1, there was no statistical difference among these two treatments. Among the CZ group, KCZ performed better as compared to ZnCZ while CZ at 1% performed poorly in terms of yield and plant biomass. In an experiment on the effect of soil application of natural zeolites on perennial rye grass, Tallai (2011) observed a 16% increase in biomass dry matter as compared to control.

The total N uptake varied from 3.19 to 9.39 g per pot in the treatments of CZ and F1 respectively (Table 6). However, the uptake by individual parts showed a different trend. As far as the uptake of N of leaf and root is concerned, ZnCZ recorded the highest value whereas the lowest uptake of N in leaf was observed in control plants. At the same time, lowest N uptake in stems was under ZnCZ and highest under F2. There was significant difference in F1 and F2 as far as stem uptake of N was considered. The share of N uptake in tuber was higher than other parts. In the tuber, the N uptake was highest with F1 treatment and

Table 5. Effect of zeolites on tuber yield and total biomass

Treatments	Tuber yield (g/plant)	Total plant biomass (g/plant)
C	113.3 ± 2.5^{b}*	147.3 ± 1.5^{c}*
F1	177 ± 11.4^{a}	221 ± 5.0^{a}
F2	167.7 ± 8.4^{a}	211.7 ± 8.5^{a}
CZ	37.7 ± 18.7^{d}	79.7 ± 19.7^{b}
KCZ	124.0 ± 7.6^{b}	167.3 ± 8.1^{d}
ZnCZ	62.7 ± 5.0^{c}	96.3 ± 6.1^{b}

Note: Mean values ± standard deviation; Means followed by the same letter are not significantly different (P = 0.05); * dry weight basis

Table 6. Effect of zeolites on NPK uptake of sweet potato

Treatments	Leaf (g/plant)	Stem (g/plant)	Root (g/plant)	Tuber (g/plant)	Total (g/plant)
			Nitrogen		
C	0.44 ± 0.03^{c}	0.71 ± 0.14^{d}	0.05 ± 0.03^{c}	2.57 ± 0.07^{d}	3.77 ± 0.21^{d}
F1	0.54 ± 0.03^{b}	$0.86 \pm 0.23d^{c}$	0.20 ± 0.01^{a}	7.79 ± 0.62^{a}	9.39 ± 0.38^{a}
F2	0.56 ± 0.06^{b}	$1.17 \pm 0.25a^{b}$	0.13 ± 0.03^{b}	4.68 ± 0.38^{b}	6.53 ± 0.25^{b}
CZ	$0.48 \pm 0.06b^{c}$	1.20 ± 0.10^{a}	0.07 ± 0.05^{c}	1.44 ± 0.69^{e}	3.19 ± 0.70^{c}
KCZ	0.53 ± 0.04^{a}	0.98 ± 0.02^{e}	$0.09 \pm 0.02b^{c}$	3.88 ± 0.42^{c}	5.48 ± 0.45^{d}
ZnCZ	$0.84 \pm 0.08b^{c}$	0.30 ± 0.07^{bc}	0.25 ± 0.03^{a}	1.80 ± 0.14^{e}	3.19 ± 0.19^{d}
			Phosphorus		
C	0.08 ± 0.01^{d}	0.11 ± 0.02^{b}	0.001 ± 0.001^{c}	0.21 ± 0.03^{d}	0.40 ± 0.03^{d}
F1	0.23 ± 0.01^{b}	0.37 ± 0.10^{a}	0.016 ± 0.002^{ab}	2.10 ± 0.22^{a}	2.71 ± 0.12^{a}
F2	0.22 ± 0.02^{b}	0.13 ± 0.01^{b}	0.027 ± 0.007^{a}	0.76 ± 0.12^{b}	1.14 ± 0.15^{b}
CZ	0.03 ± 0.01^{e}	0.06 ± 0.01^{bc}	0.024 ± 0.015^{a}	0.23 ± 0.10^{cd}	0.35 ± 0.10^{d}
KCZ	0.18 ± 0.01^{c}	0.10 ± 0.001^{b}	0.007 ± 0.002^{bc}	0.42 ± 0.07^{c}	0.71 ± 0.08^{c}
ZnCZ	0.38 ± 0.02^{a}	0.02 ± 0.01^{c}	0.020 ± 0.003^{ab}	0.16 ± 0.03^{d}	0.58 ± 0.03^{c}
			Potassium		
C	0.43 ± 0.04^{cd}	0.41 ± 0.08^{c}	0.01 ± 0.01^{b}	3.51 ± 0.22^{b}	4.37 ± 0.19^{b}
F1	0.70 ± 0.06^{b}	0.75 ± 0.19^{b}	0.13 ± 0.01^{a}	2.95 ± 0.26^{c}	4.54 ± 0.13^{b}
F2	0.81 ± 0.09^{b}	0.70 ± 0.15^{b}	0.10 ± 0.02^{a}	4.50 ± 0.35^{a}	6.10 ± 0.33^{a}
CZ	0.40 ± 0.04^{d}	0.95 ± 0.08^{a}	0.09 ± 0.06^{a}	0.88 ± 0.42^{e}	2.32 ± 0.45^{c}
KCZ	0.55 ± 0.04^{c}	0.78 ± 0.05^{ab}	0.10 ± 0.02^{a}	4.50 ± 0.17^{a}	5.93 ± 0.20^{a}
ZnCZ	0.98 ± 0.07^{a}	0.18 ± 0.04^{d}	0.08 ± 0.01^{a}	1.55 ± 0.20^{d}	2.79 ± 0.24^{c}

Note: Mean values ± standard deviation; Means followed by the same letter are not significantly different ($P = 0.05$)

lowest under CZ. Though nitrogen uptake in leaf and root was high in soils treated with ZnCZ, its uptake in tubers was not superior.

The total P uptake was highest under F1 treatment and lowest under soils received CZ. This was again due to the huge share of P uptake in tuber as compared to other parts and hence on the total uptake. However, F1 was superior among the treatments as far as uptake in leaf and stem were concerned, whereas F2 was superior for P uptake by root.

Total potassium uptake ranged from 2.32 to 6.10 grams per pot under CZ and F2 respectively. The KCZ performed equally superior as that of F2. However, ZnCZ accounted for maximum K uptake in leaf whereas CZ accounted for maximum in stem. F1 was superior in K uptake in roots.

The overall mean NPK uptake efficiency values were 126.6, 136.9 and 121.6 % respectively which indicated that P uptake efficiency was higher than N and K. The N uptake efficiency ranged from 72.9 to 214.1 % under CZ and F1 respectively (Table 7). The treatments of C, CZ and ZnCZ are at par with each other whereas F2 is significantly lower than F1. The P uptake efficiency also showed the same trend in treatments as that of N uptake and a large difference in uptake efficiency was noted in F1 as compared to control. As far as K uptake efficiency is concerned, F2 was highest with 171 % while CZ was lowest with 65.1%. There was no significant difference in K uptake efficiency among control and F1 treatments. Overall, the study indicated the beneficial effect of fly ash zeolite could be due to the low cation exchange and coarse texture nature of laterite soil where the need for the improvement in nutrient retention and moisture holding capacity is greater (Bob Wiedenfeld, 2003).

Table 7. Effect of zeolites on nutrient uptake efficiency

Treat-ments	Nutrient Uptake Efficiency (NUpE)		
	N	P	K
C	85.8 ± 4.8^{d}	49.8 ± 3.8^{d}	122.7 ± 5.3^{b}
F1	214.1 ± 8.2^{a}	337.5 ± 14.7^{a}	127.2 ± 3.8^{b}
F2	148.0 ± 6.0^{b}	142.2 ± 17.8^{b}	171.0 ± 9.3^{a}
CZ	72.9 ± 15.9^{d}	44.0 ± 12.9^{d}	65.1 ± 12.8^{c}
KCZ	125.3 ± 10.4^{c}	89.1 ± 10.1^{c}	166.1 ± 5.6^{a}
ZnCZ	72.9 ± 4.6^{d}	72.1 ± 4.3^{c}	78.4 ± 6.8^{c}

Note: Mean values ± standard deviation; Means followed by the same letter are not significantly different ($P = 0.05$)

Conclusion

The study has shown the pH buffering effect and beneficial action of fly ash based zeolites in maintaining a near neutral pH condition for successful cultivation of sweet potato in acid, laterite soils. The excess sodium content of pH treated commercial zeolites (CZ) had a negative influence on plant growth and yield despite of advantages in moisture holding and cation exchange properties. Though additions of fly ash zeolites to soil at 2% level was found to benefit soil exchangeable K, number of branches, total uptake of potassium and high nutrient uptake efficiency as compared with 1%, the tuber yield among the two treatments was on par. Hence application of fly ash zeolites to soils at 1% rate could be beneficial for sweet potato production in laterite soils. The study also indicated the scope of utilizing the fly ash based zeolites as a slow release fertilizer for which intense studies on charge persistence and its relationship with nutrient holding properties in respect of NH_4^+, K^+, Ca^{++} has to be taken up in order to effectively utilize this soil conditioner for better tuber crops production especially in low quality soils.

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References

Amrhein, C., Haghnia, G.H., Taisoon, K., Mosher, P.A., Gagajena, R.C., Amanios,T., La, T.L.De., Kim, T.S and Torre, L. 1996. Synthesis and properties of zeolites from coal fly ash. *Envtl. Sci Technol*. **30** (3): 735-742.

Bob Wiedenfeld. 2003. Zeolite as a soil amendment for vegetable production in the lower Rio Grande valley. *Subtropical Plant Sci*. **55:** 7-10.

Fansuri, H., Pritchard, D. and Zhang, D. 2008. Manufacture of low grade zeolites from fly ash for fertilizer applications. Report No. 91. Centre for fuels and energy, Curtin University of technology, Australia.

Ge, G., Li, Z., Fan, F., Chu, G., Hou, Z. and Liang, Y. 2010. Soil biological activity and their seasonal variations in response to long-term applications of organic and inorganic fertilizers. *Pl. Soil*. 326: 31-44.

Ghodrati, M., Sims, J.T. and Vasilas, B.S. 1995. Evaluation of fly ash as a soil amendment for the Atlantic coastal plain. Soil hydraulic properties and elemental leaching. *J. Water Soil Air Pollut*. **81**: 349-361.

Hershey, D.R., Paul, J.C. and Carlson, R.M. 1980. Evaluation of potassium enriched clinoptilolite as a potassium source of potting media. *Hort. Sci*. **15:** 87-89.

Loks, N.A., Manggoel, W., Daar, J.W. and Mamzing, D. 2014. The effects of fertilizer residues in soils and crop performance in northern Nigeria: a review. *Int. Res. J. Agric. Sci. Soil Sci*. **4** (9): 180-184.

National Horticulture Board. 2013. Area and production statistics. National Horticulture Board, Available in: http://nhb.gov.in/OnlineClientrptProduction.aspx

Page, A.L., Elseewi, A.A. and Straughan, I.R. 1979. Physical and chemical properties of fly ash from coal fired power plants with special reference to environmental impacts. *Residue Rev*. **71:** 83-120.

Polat, E., Karaca M., Demir, H. and Naci-Onus. 2004. Use of natural zeolite (clinoptilolite) in agriculture. *J. Fruit Ornamental and Pl Res*. **12**: 183-189.

Seilsepour,M. and Rashidi, M. 2011. Prediction of soil sodium adsorption ratio based on soil electrical conductivity. *Middle-East J. Sci. Res*., **8** (2): 379-383.

Sugianto, R. 2005. Dampak Aplikasi Penggunan Campuran Zeolit an Pupuk Terhadap Produksi Ubi Jalar. *J. l Zeolite Indonesia*., **4** (2): 86-90.

Tallai, M. 2011. *Effect of Bentonite and zeolite on characteristics and change of microbial activity of acidic humic sandy soil*. PhD thesis. University of Debrecen, Hungary.