

Dept

UNIVERSITY OF ZAMBIA

**IMPROVEMENTS TO SOIL CATION EXCHANGE CAPACITY
FOLLOWING ADDITIONS OF VARIOUS FORMS OF SOIL
AMENDMENTS.**

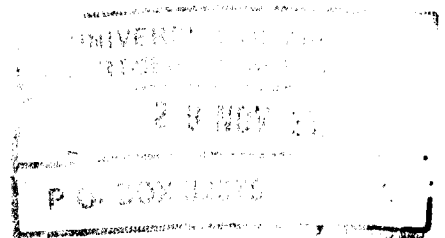
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A PROJECT REPORT

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Dedication

A dedication to my senior friend, the late Mutale S. Chinkutele, so untimely taken away on Saturday, 9th November 2002.

Acknowledgements

Firstly, I would like to register my sincere acknowledgements to Dr. O.A. Yerokun for adequately supervising my work. Secondly, I say sincere thanks to Dr. D. Nkonde and Mr. V. Kawamya both of School of Mines for supplying me with some materials used in this exercise. I also thank Mr. K. Mashuta, Dr.Mwanamwenge and Mr. Msiska all of Kabwe Research Station for the unfailing material and technical assistance they rendered to me during preparation of the report. Special thanks to my course mates as well for the good company I enjoyed with them, especially Mr. Manjolo Nyambe, Mr. Brian Chimbanga and the late Micheal Kumwenda.

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ABSTRACT

Low cation exchange capacities (CEC) contribute to the low productivity of some Zambian soils. By modifying these soils with cation exchangers, nutrient retention and crop productivity may be improved. A pot experiment was done in the greenhouse to investigate the effectiveness of various amendments in improving soil cation exchange capacity (CEC) and reducing leaching of applied potassium. Bentonite, Charcoal, Compost and Zeolite were each added to a Mufulira series soil at two different application rates (12.5g kg^{-1} and 25g kg^{-1}), and a control to give a total of nine treatments. The treatments were replicated three times in a Randomised complete block design (RCBD). Two crops of maize were each grown for six-week periods, in pots. Potassium (0.9g / pot) was applied to the soils a week after the first planting and there after subjected to leaching at 1, 5 and 11 weeks after application. The treated soils were analysed for CEC and $\text{pH}_{(\text{CaCl}_2)}$ while the dry matter yields of crops were obtained. Leachates were analyzed for potassium concentration.

Soil CEC was improved ($P \leq 0.05$) by all the amendments, rising from $3.57\text{ cmol (+) kg}^{-1}$ to $5.71\text{ cmol (+) kg}^{-1}$ and $6.14\text{ cmol (+) kg}^{-1}$ (Bentonite, 12.5g and 25g kg^{-1} of soil respectively), $4.88\text{ cmol (+) kg}^{-1}$ and $5.61\text{ cmol (+) kg}^{-1}$ (Charcoal, 12.5g and 25g kg^{-1} of soil respectively), $5.39\text{ cmol (+) kg}^{-1}$ and $6.03\text{ cmol (+) kg}^{-1}$ (Compost, 12.5g and 25g kg^{-1} soil respectively) and $4.89\text{ cmol (+) kg}^{-1}$ (Zeolite at both rates). These improvements were significantly different between treatments ($P \leq 0.05$). Increasing the rate of soil amendment was positive in increasing CEC. As soil CEC increased, the K lost in the leachate decreased. All the pots showed an increase in pH with the addition of K, but not as a result of CEC values. Treatments did not significantly affect dry matter yield ($P \leq 0.05$).

1.0. INTRODUCTION

Agricultural production in Zambia is becoming increasingly costly because of the declining soil fertility. In order to achieve reasonable yields, large additions of fertilizer are required. This is because most soils have inherently low fertility and a problem of low nutrient retention capabilities. However, for the supplied nutrients to be retained and available for plant use, the soil exchange capacity is important. Cation exchange capacity (CEC) is an indication of the ability of the soil to retain cations and subsequently release them into soil solution through ion exchange. This parameter is measured in centi-moles of charge per kilogram of soil ($\text{cmol } (+) \text{ kg}^{-1} \text{ soil}$). It enables soil to act as a reservoir of cationic nutrients.

Soils low in CEC have low nutrient retention capacities. This condition is prevalent in the soils of the high rainfall areas of Zambia (Solberg, 1985). According to the soil map of Zambia, about 44,840,000 hectares of the 74,833,000 hectare land base are mostly oxisols and ultisols (Veldkamp, 1987). These soils are rich in low activity clays such as kaolinite, a non-expanding clay with very low surface charge. They are strongly leached and chemically poor soils. Their agricultural productivity is low (Lungu, 1987).

With poor management, increased soil acidity and other forms of degradation have been reported to further reduce CEC to less than 16 $\text{cmols } (+) \text{ kg}^{-1} \text{ soil}$ (Mapiki and Phiri, 1995). Cation exchange capacities in this range are described as low. Therefore, it would be useful to try to raise soil CEC. This improves the natural retention of nutrients and ultimately agricultural productivity.

Low nutrient retention and high leaching conditions of soil require heavier applications of fertilizers to get reasonable crop yields. These conditions impose a combined effect of low production in low external input farming

and making production more costly due to the high external input requirements. From discussions with some low input producers in Mansa, it was learnt that maize yields as low as 0.65 tons per hectare are obtained. The financial or economic returns from such yields are far much lower than the costs of production.

Today, much needs to be done to improve existing agricultural production systems. This is in response to the increasing world population and its demand for food, fibre and oils. Consequently, there is need for agricultural researchers to provide farmers with ideas to produce more from the same landbase while the quality of the environment and the natural resources are being conserved.

Evidence has suggested that surface charge of soils can be altered by chemicals commonly used as fertilizers and soil amendments (Wann and Uehara, 1978). The following greenhouse study was carried out to determine the effectiveness of Zeolite, Bentonite, Charcoal and Compost in improving soil cation exchange capacity, reducing cation (K) leaching and influencing dry matter yield of maize.

2.0 LITERATURE REVIEW

2.1 Concept of Cation Exchange Capacity

Soil CEC is one of the several mechanisms in soil which tie up and release ions in soil solution. Ions may then be transported to the plant root interface by mass flow, root interception or ionic diffusion (Baweja and Mclean, 1975). Soil CEC is contributed by the existence of negative charges on soil colloids (Russell, 1973). The charges result from the isomorphous replacements of cations in the clay lattices, and from humus. In humus, charge originates from dissociation of hydrogen ions from functional groups at particle surfaces and within particles. Nhamo (2000), showed that a reduction of soil organic matter led to lower CEC in the soil.

Soil particle surface charges arise from defects in the interior of these particles, or from the adsorption of hydrogen and hydroxyl ions, which are the potential determining ions. If charge results from the internal defects, it is permanent. Permanent charge is generally negative. The net surface charge resulting from adsorption of the potential determining ions is either positive, negative or neutral (Gillman and Uehara, 1980). Soil CEC can also be defined as a product of the specific surface area of the soil and the charge density. In a soil with both permanent and variable charge, CEC is expressed as:

$$CEC = S_p O_p + S_v O_v$$

where, S_p – is the specific surface area under permanent charge

O_p – is the permanent charge density

S_v – is the specific surface area under variable charge

O_v – is the variable charge density.

Soil CEC values in the range of 26 to >40 cmols (+) kg⁻¹ are high to very high, 16 to 25 cmols (+) kg⁻¹ are medium and 15 to 6 cmols (+) kg⁻¹ are low to very low (Ilaco, 1985).

Cation nutrients are attracted to the negatively charged sites. Those held but still available for plant use are said to be exchangeable. Those that are so strongly held that they are not available for plant use are non-exchangeable or fixed. The fixed elements are not part of the quantified CEC of a particular soil. For instance, the potassium ions in the sheet structures of illite, are fixed. Meanwhile, the exchangeable forms on colloids, and the soluble potassium are the two major immediate sources of the element to plants (Russell, 1973).

The process of liming is based on cation exchange reactions. Here, the exchangeable hydrogen and aluminum ions on the colloidal complex are exchanged with the calcium and other cations in the lime to increase soil pH (Brady, 1999).

2.2 Oxisols and Ultisols

Oxisols and ultisols are highly weathered soil orders, with a light colour, low in organic matter content and low base saturation. They have very low basic cation contents, but are rich in colloidal particles dominated by hydrous oxides of aluminum and iron, rendering an acidifying effect and predominantly low inherent CECs. These soils have a clay content that is of the non-sticky type, indicative of the ease of leaching by percolating water. Agricultural production on most of these soils requires high fertilizer applications due to the inherent deficiencies of phosphorus, nitrogen and micro-nutrients. In certain places, keeping the land under forest cover is the best land-use type on these soils (Brady, 1999).

Though oxisols and ultisols have crystalline kaolinitic clay types with a net negative charge, the amorphous hydrous oxides of iron and aluminum have a more dominant net positive charge giving the clay a net positive charge also. This renders the soil a low capacity to hold cations. The lack of weatherable minerals or their existence in trace amounts limits the

basic cation supply in these soils. They may be found in the limited cation exchange complexes in plant tissue residues and in very deep less weathered soil layers. In general, oxisols and ultisols are soils with a low inherent fertility status, and when cleared and cultivated there is a noticeable decline in crop yields (Brady, 1999).

Ultisols are deep, well-drained, red or yellow soils with less desirable physical and chemical properties. They have a base saturation of less than 35 %. Their native fertility is relatively low (Sanchez, 1976).

Sys (1979) reported that clay minerals in oxisols and ultisols are of the kaolinitic family. Practically, kaolinite has no ionic substitutions in it. Hence, permanent charges in it are few. During the ferralitic weathering process, the charges become saturated with aluminum. However, at higher pH, supplementary charges develop. They develop by deprotonation of hydroxyl groups on aluminum hydroxide.

2.3 Zambia Agro-ecological Region III soils

Zambia is divided into three (3) agro-ecological regions based on climate and soils. Oxisols and ultisols are predominant in agro-ecological region (III). They are subjected to heavy rainfalls and high temperatures, hence they are highly weathered and leached (Veldkamp, 1987).

Mapiki and Phiri (1995) reported that the highly weathered and strongly leached upland soils cover about 43 % of the high rainfall areas (Region III). These are areas where rainfall exceeds 1200 mm per annum. They developed from acid rocks under high rainfall and high temperatures. These soils are strongly acidic, very poor in nutrients, and are considered the most problematic. They are low activity clay soils with the CEC ranging between 5 and 13 cmol (+) kg⁻¹, salt exchangeable pH of 4.5 or below, a low base saturation (< 35 %), very high in free iron (III) ions, and a high

aluminum saturation which sometimes exceeds 60 % in the sub soil. Texture is from sandy clay loams to clayey, with weak to porous and occasionally moderate structures. Low fertility status, acidity, aluminum toxicity, high phosphate sorption and soil erosion are major constraints to crop production here.

Solberg (1985) reported that the high rainfall areas of Zambia have some of the poorest soils for crop production. They are acidic and have low storage capacity for nutrients. They sometimes contain five times the manganese contents of average soils.

Poor soil fertility has been blamed for the relatively poor development of permanent agriculture in the high rainfall areas of Zambia. The region has been less attractive for large-scale commercial farming. Improvements of, or alternatives to the traditional shifting farming systems are required in order to sustain production in permanent systems (Lungu, 1987).

2.4 Amending soils to improve CEC

When organic matter is decomposed, it transforms into humus. This material has average CEC between 150 and 300 cmol (+) / kg (Bohn et al., 1985). Because of its extremely small particle sizes, humus has a large surface area per unit weight. It also exhibits surface charges that attract charged ions. The humic micelles carry a swarm of adsorbed cations, enhancing the nutrient holding capacity of the soil (Brady, 1999).

Slattery and Carmody (2001) reported that addition of composted manure to soil increased soil pH. This was primarily due to proton exchange with basic cations. Also, an increase in soil organic carbon content increased the buffer capacity of the soil. Thus, organic carbon materials provide an alternative to lime and increase the soil's resilience to resist acidification, beyond that of liming.

When Boniao (2000) incubated some soils with calcium silicate, ground basaltic pyroclastics or peat, he observed that soil CEC was improved only under long incubation periods. Plant response to the amendments showed that nutrient uptake was positively related to the improved ion retention of the soil. It also showed that relative heights and weights were linearly correlated with cation concentrations in the soil solution.

Mackellar (1990) applied coal fly ash, an amorphous ferro-alumino silicate material to some sandy soils. He observed that soil moisture was substantially increased within the ash band compared to the surrounding sands. Further, maize growth (plant height, leaf area, grain yield) was significantly better in the ash treated plots.

Weber et al. (1968) showed a positive adsorption of herbicides by charcoal, but the ions were readily desorbed by distilled water.

3.0 MATERIALS AND METHODS

3.1 Soil

The soil used is classified as a Mufulira series, Mixed Isohyperthermic Typic Kandistult (Yager, 1967). It is a loamy sand with 6% clay, 13% silt and 81% sand. Soil $\text{pH}_{(\text{CaCl}_2)}$ was 5.09. Some other characteristics are given in Table1.

Bulk sample was collected from the Ap (0-20cm) horizon of a sorghum field, at Mansa Research station, in February 2002. This was transported to the laboratory, air-dried and sieved to pass through a 2mm sieve.

Table1. Some characteristics of a Mufulira soil determined before treatment applications.

Parameter	Value
pH- H_2O	5.69
Organic Matter	1.2 %
CEC	4.0 cmol (+) kg^{-1}
Calcium	58.4 mg / kg
Potassium	24.0 mg / kg
Magnesium	20.7 mg / kg
Manganese	30 mg / kg
Aluminum	27 mg / kg
Iron	16 mg / kg
Zinc	1.09 mg / kg
Copper	0.45 mg / kg
Phosphorus	0.70 mg / L
Bulk density	1.4 g / cm^3
Field moisture capacity	13.2 % by weight

3.2 Amendments

a) Compost: Compost was processed at the School of Agricultural Sciences Field Station. Crop residues and cow dung were moistened and laid in a heap. The heaps were consistently turned at intervals. After three months, it was collected as mature compost. It was loosened with hands. This material had a CEC of 36 cmol (+) kg⁻¹.

b) Charcoal: Charcoal was purchased from the market. It was pounded to fine powder in a mortar, giving a CEC of 20cmol (+) kg⁻¹.

c) Zeolite: Zeolite was obtained from School of Mines. An X-ray diffraction analysis revealed it as sodium aluminum silicate hydrate or natrolyte. It was crushed in a geo-crusher and had a CEC of 12 cmol (+) kg⁻¹.

c) Bentonite: Bentonite clay was collected from School of Mines. This material had a CEC of 42 cmol (+) kg⁻¹.

All the four amendments were sieved to pass through a 2mm sieve.

3.3 Greenhouse study

A pot study was conducted in the School of Agricultural Sciences greenhouse at the University of Zambia, between 4th July and 4th October, 2002. Two kilograms each of soil were placed in pots with free drainage. Each of the four amendments was added respectively to soil in the pots at rates of 12.5g kg⁻¹ and 25g kg⁻¹, and mixed thoroughly. A Control pot without an amendment was also included to give nine treatment combinations. The treatments were replicated three times and arranged in a Randomized Complete Block Design. Each pot was watered to field capacity before planting three seeds of maize.

One week after planting, 2g of chemical grade potassium sulphate (K_2SO_4) was applied to each pot to supply 0.9g of K. The pots were watered at three to four day intervals to 80% of field moisture capacity. Another week after applying K, the pots were subjected to leaching with about 210ml of distilled water. Leachate was collected and stored in a refrigerator before analysis. Further similar leaching of the soil was done four weeks later. At the same time, the first crop, then in its sixth week was harvested by removing tops plus roots from the soil. These were separated and dried in an oven at 65 °C. The dry matter was weighed.

A second crop of maize was planted just as the first one was harvested. Three seeds of maize were planted and harvested after six weeks growth. The pots were watered as in the first crop. At the time of harvest, the soils were again leached with 210ml of distilled water and leachate stored before analysis for K. Soil samples were collected from each pot after mixing in the amendments, at the end of the first crop and at the end of the second crop. These were analysed for CEC and pH.

3.4 Sample Analysis

3.4.1 Cation Exchange Capacity

The Displacement or Batch method of soil CEC determination was used. It involved saturation of a 2g soil sample with 20ml of a 1 N ammonium acetate solution, centrifuging and decanting the supernatant. This was repeated three times. Then, the excess saturating solution was eliminated by washing the soil with 15ml of alcohol and carefully decanting. Adsorbed index ions were determined by steam distillation of ammonium (NH_4^+) as ammonia (NH_3) and titration with 0.01 N hydrochloric acid (HCl) using a boric acid indicator. The amount of extracted index cations per unit dry weight of soil is equivalent to the CEC of the soil.

3.4.2 Potassium

Potassium concentration in leachates was determined on an atomic absorption spectrophotometer.

3.4.3 Soil pH

To determine pH, 10g of soil was equilibrated with 25 ml of 0.01 M calcium chloride and shaken for 30 minutes. Readings were done using a glass electrode.

3.5 Statistical Analysis

Analysis of variance was done using MSTAT computer package. Duncan's Multiple Range Test was used to separate treatment means. Correlation coefficients were determined using Microsoft Excel.

4.0 RESULTS AND DISCUSSION

4.1 General observations

The experiment was conducted in the period between 4th July and 4th October 2002. The temperature range in the glass house in this period was between 22 and 42 °C, reaching the peak around 13 and 14:00 hours. The soils under different treatments exhibited varied moisture characteristics. While water was applied at the same time to all the units, plants growing in the pots treated with Bentonite (a clay), usually withered in between the 3 to 4 day irrigation cycles. Brady (1999), showed that moisture in clays was strongly attracted to adsorbed cations and some of it was held in internal surfaces of clay colloids, making it less available to plants. On the other hand, pots treated with Charcoal remained wet for longer than any other treatment.

The two crops exhibited nitrogen and phosphorus deficiencies at some stage. They however responded quickly to applications of 0.05g N / pot and 0.01g P / pot, supplied as ammonium nitrate (NH_4NO_3) and sodium phosphate (Na_3PO_4) respectively.

4.2 Soil CEC

Results of changes in the cation exchange capacity of the soil under different amendments are as shown in table2. All the amendments significantly ($P \leq 0.05$) improved soil CEC. Because CEC values were not statistically different between the various times of sampling, the mean values are used for further discussion. Generally, increasing the rate of amendment improved soil CEC, except when Zeolite was used. Bentonite treatments appeared most effective, raising soil CEC from 3.57 cmol (+) kg^{-1} to 5.71 cmol (+) kg^{-1} and 6.14 cmol (+) kg^{-1} , with 12.5g and 25g

material respectively. This observation was agreeable with the higher CEC of Bentonite (42.0 cmol (+) kg⁻¹).

Table 2. Cation exchange capacities of a Mufulira soil amended with cation exchangers and measured at three intervals.

Treatment	Rate (g kg ⁻¹)	CEC*			
		T1	T2	T3	Mean* *
		(cmol kg ⁻¹)			
Control	0	3.50	3.70	3.50	3.57d
Charcoal	12.5	4.48	4.92	5.25	4.88c
	25	4.27	5.60	6.50	5.61abc
Compost	12.5	5.17	5.18	5.83	5.39bc
	25	7.17	5.42	5.50	6.03ab
Bentonite	12.5	6.00	5.22	5.92	5.71ab
	25	6.67	6.33	5.42	6.14a
Zeolite	12.5	5.27	4.67	4.74	4.89c
	25	4.82	4.62	5.25	4.89c

* T1, T2, T3 = 1st, 2nd and 3rd soil samples, respectively.

** Means with the same letter are not significantly different by the Duncan's Multiple Range Test.

Compost treatments ranked next, raising soil CEC to 5.39 and 6.03 cmol (+) kg⁻¹, with 12.5 and 25g, respectively. Again, compost CEC of 36.0 cmol (+) kg⁻¹ ranked after bentonite. Charcoal treatments raised CEC to 4.88 and 5.61 cmol (+) kg⁻¹, respectively and charcoal CEC was 20.0 cmol (+) kg⁻¹. Zeolite with the lowest CEC (12 cmol (+) kg⁻¹) was just as good as charcoal (Table2).

The results with these treatments show that increasing rates of material improved soil CEC. Figures 1 and 2 further confirm that the ranking could be Bentonite (0.1) > Compost (0.09) > Charcoal (0.08) > Zeolite (0.05) as described by their coefficients.

Gillman and Uehara (1980) showed that soil CEC is a product of the surface area of a given soil mass and it's charge density. Similarly, from

the figures, it was deduced that soil CEC was a function of the initial CEC of the amendment used, and its application rate. The higher the initial CEC of an amendment, the higher was the charge density in its quantity, applied to the soil. Also, increasing application rate increased its content in soil, hence, the surface area of the soil also increased. Zeolite was supplied in ore form. So, as its application rate increased, the impurity content also increased. Hence, its efficiency at 25g kg^{-1} was lower than at 12.5g kg^{-1} of soil.

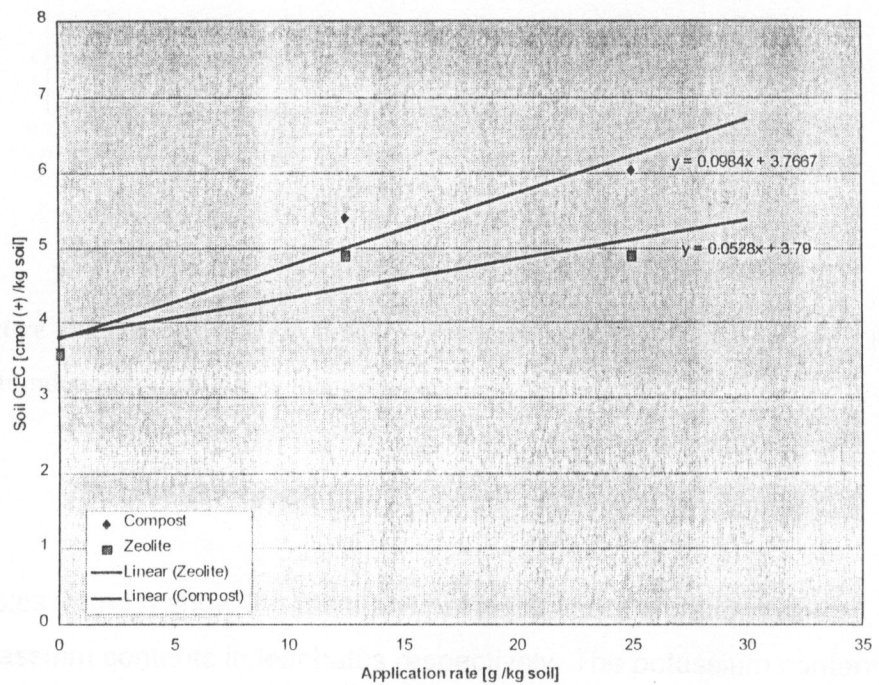


Figure 1. Linear correlation between application rates of Zeolite and Compost with induced soil cation exchange capacities.

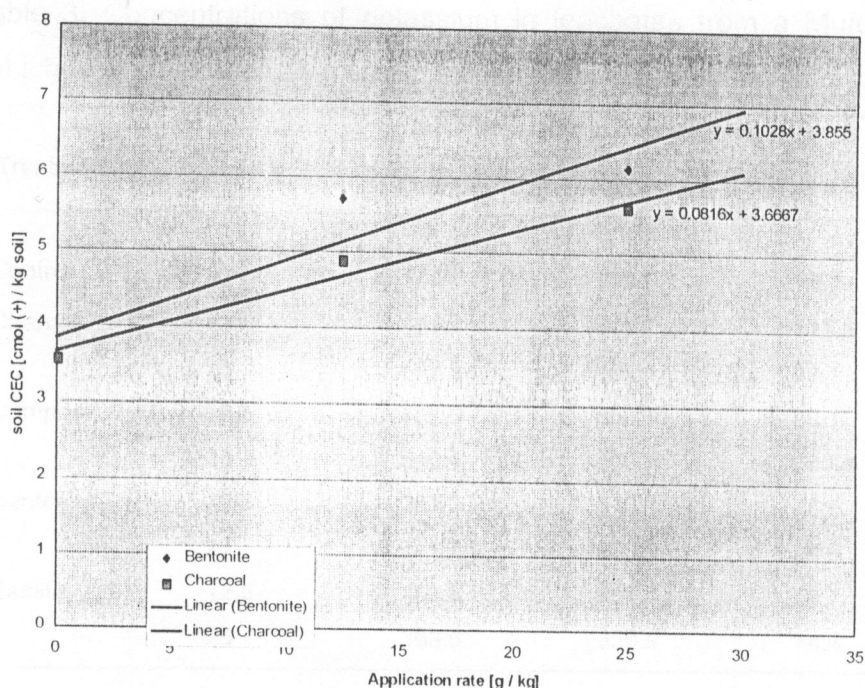


Figure 2. Linear correlation between application rates of Bentonite and Charcoal with induced soil cation exchange capacities.

4.3 Potassium leaching

Tables 3 and 4 show the results of potassium concentrations, and potassium contents in leachates respectively. The potassium content of a given leachate was determined as a product of it's concentration and volume (210ml) of water used. Due to logistical challenges, leachate from each pot was not analyzed, but a volumetric average was used.

Table 3. Concentrations of potassium in leachates from a Mufulira soil, which was amended using cation exchangers and supplied with 0.9g K.

Treatment	Rate	Potassium concentrations		
		Week 1	Week 5	Week 11
	(g kg ⁻¹)		(mg L ⁻¹)	
Control	0	477.7	651.0	83.8
Charcoal	12.5	451.1	607.7	113.5
	25	692.2	669.5	99.1
Compost	12.5	411.3	688.9	80.1
	25	540.4	336.9	290.8
Bentonite	12.5	261.2	513.8	78.5
	25	281.3	333.0	94.5
Zeolite	12.5	463.6	667.5	56.7
	25	363.6	329.9	84.6

Table 4. Cumulative potassium contents in the leachates from a Mufulira soil, which was amended using cation exchangers and supplied with 0.9g K.

Treatment	Rate	Potassium contents		
		Week 1	Week 5	Week 11
	(g kg ⁻¹)		(mg)	
Control	0	100.9	238.3	256
Charcoal	12.5	95.2	223.4	247.34
	25	146.1	287.4	308.3
Compost	12.5	86.8	232.2	249.1
	25	114	185.1	246.5
Bentonite	12.5	55.1	167.8	187.8
	25	59.4	129.7	149.6
Zeolite	12.5	97.3	238.6	250.6
	25	76.7	146.3	164.2

Table 3 shows that all the treatments, except for the Charcoal at 25g kg⁻¹ of soil, lost less potassium than the Control.

Figure 3 shows the distribution of potassium, cumulatively leached from the Control (D), soil treated with Charcoal (C) and Bentonite (A).

A week after application of potassium sulphate, 100.9mg of K were observed in the leachate from the Control. In the second leaching exercise in week 5, 238.3mg K was lost. At the last leaching, the Control lost 256mg of K. From the soil treated with Charcoal at 12.5g kg⁻¹, 95.2mg K was leached in the first week. Following the second and third leachings, 223.4mg K and 247.3mg K were leached, respectively. Leachate from soil treated with Bentonite at 25g kg⁻¹ contained 59.4mg of potassium at first leaching. At the second leaching, 129.7 mg K was collected and at the third leaching, 149.6mg K was leached out.

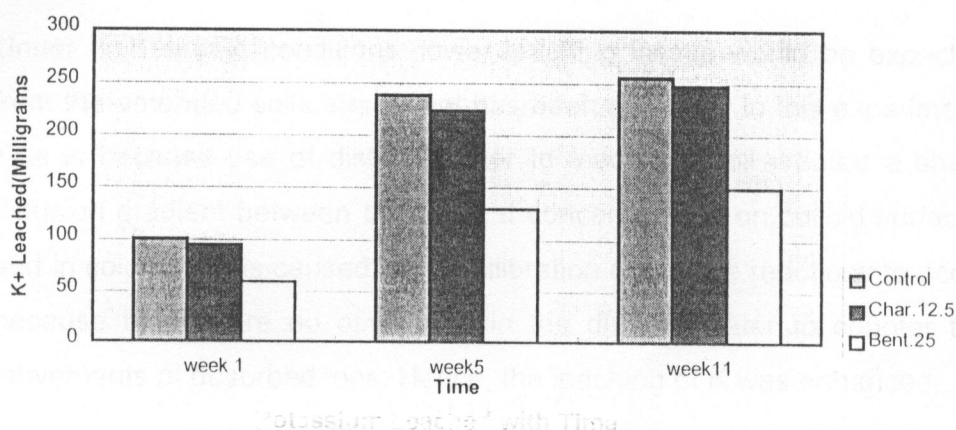


Figure 3. Potassium leaching losses from a Mufulira soil amended with bentonite and charcoal.

The trend in leaching reduction following the amendment of soil was an indication of the increasing adsorption of potassium in soil as well as the strength of adsorption contributed by the treatment. Adsorption and prevention of leaching of added nutrient cations was shown to increase

with increasing soil CEC (Brady, 1999). Thus, the Bentonite treatment, which apparently had the highest CEC, correspondingly adsorbed more. It probably leached less K because it is a clay with strong adsorption strength. Conversely, the Control, with the lowest CEC, leached the highest amount of potassium, because there was no further contribution to adsorption strength.

The amount of K leached from soil treated with charcoal, was relatively high because as (Weber, 1968) showed, cations can be desorbed from charcoal with water. It appears to have a lower strength of adsorption.

So, taking this observation period for a growing season, with an assumption that the Control was significantly depleted, the amended soils would still contain some added potassium. The retained potassium would be available to the next crop grown. This carry-over effect reduces the amount of potassium fertilizer that would be needed in the next season.

Under normal field conditions, lower leaching losses would be expected from the amended soils, than what has been observed in this experiment. This is because use of distilled water to leach the soil created a sharp diffusion gradient between the nutrient concentrations on colloid surfaces and in solution. This caused fast equilibration exchange reactions to occur because there were no other ions in the distilled water to counter the movements of desorbed ions. Hence, the leaching of K was enhanced.

4.4 Soil pH

Results for soil pH determined at six weeks (pH1) and at twelve weeks (pH2) are shown in table 5. There was a general increase in soil pH in all the treatments, with significant differences between them ($P \leq 0.05$) at pH1. The soil amended with charcoal at 12.5g kg^{-1} recorded the highest pH value of 7.53. The same amendment at 25g kg^{-1} recorded a pH of

7.45. Thus, charcoal at both rates increased soil pH from moderate acidity (pH 5.69) to the alkaline range (pH > 7). All the other treatments including the control, recorded pH values in the neutral range (between 6 and 7).

Table 5. pH of a Mufulira soil amended using cation exchangers.

Treatment	Rate (g kg ⁻¹)	Soil pH	
		pH1	pH2
Control	0	6.18	6.06
Charcoal	12.5	7.53	6.10
	25	7.45	6.14
Compost	12.5	6.60	6.09
	25	6.74	6.17
Bentonite	12.5	6.59	6.05
	25	6.93	6.17
Zeolite	12.5	6.27	6.02
	25	6.59	6.04
LSD _{0.05}		0.19	NS

NS – No significant differences between treatments occurred at $P \leq 0.05$.

At pH2, values lower than at pH1 were observed in all the treatments, with no significant differences between them at $P \leq 0.05$. The pH values in both charcoal treatments reduced from the alkaline to the neutral range, while the rest of the treatments persisted in the neutral range.

Although Russell (1973), showed that increasing soil CEC increased soil pH by adsorption of acidifying elements, a correlation analysis at $P \leq 0.05$ showed that there was no relation between soil CEC and soil pH at both times (pH1 and pH2). This result concurred with Boniao's (2000), who showed that soil amendments took long to effect certain changes in soil. Thus, the observed increases in soil pH probably resulted from the addition of potassium (a base) to the soil. Miller and Donahue (1995) showed that increasing adsorption of basic cations in a soil increased it's

pH. Also, some amendment materials used are known to be alkaline. For instance, charcoal was said to contain alkaline ash, which caused soil pH to rise.

Thus a heavy K fertilisation coupled with a good adsorption environment caused a liming effect on soil. The likely cause of the reductions in soil pH at pH2 was the reduction in base saturation following the leaching of potassium.

4.5 Dry Matter

Table 6 shows results of the dry matter yields of two six week maize crops, C1 and C2. For both crops, there were no significant differences in mean dry matter yields in all treatments at $P \leq 0.05$.

Table 6. Dry matter yields of maize grown in pots with soil amended using cation exchangers.

Treatment	Rate	Dry matter yield		
		C1	C2	Total
	(g kg ⁻¹)		(g)	
Control	0	5.20	4.90	10.10
Charcoal	12.5	5.60	4.80	10.40
	25.0	5.40	5.00	10.40
Compost	12.5	5.03	4.70	9.73
	25.0	5.80	5.00	10.80
Bentonite	12.5	4.40	4.60	9.00
	25.0	4.80	4.43	9.23
Zeolite	12.5	4.80	4.70	9.50
	25.0	5.00	5.20	10.20
LSD _{0.05}		NS	NS	NS

Soil treated with Compost at 25g kg⁻¹ had the highest dry matter yield for crop 1. This was probably because nitrogen and phosphorus deficiencies were less severe in this treatment (from visual diagnosis). In crop 2, the

deficiencies were evenly distributed in all the treatments. However, no K deficiencies or tissue weakening, as described by Tisdale et al. (1975), were observed in both crops. This showed that the crops were supplied with enough potassium.

An analysis at $P \leq 0.05$ showed that there was no correlation between soil CEC and dry matter yield. The poor responses to soil CEC improvements by the two crops were caused by the nitrogen and phosphorus deficiencies they suffered. Thus, as has been shown by Tisdale (1975) and others, improving one soil condition is no guarantee of a good crop yield, because of the possible limiting effects of the numerous factors that affect plant growth.

5.0 CONCLUSION

The results of this experiment indicate that the amendments Bentonite, Charcoal, Compost and Zeolite increased the cation exchange capacity of the soil. The effectiveness of each was a function of its initial CEC and the application rate.

Bentonite, at 25g kg⁻¹ was the best amendment. However, its effects at both application rate, did not differ significantly at $P \leq 0.05$. Both at 25g kg⁻¹ application rates, the amendments Bentonite and Compost shifted the soil from a class of very low CEC soils, which have CEC values of less than 6 cmol (+) kg⁻¹, to that of low CEC soils which have CEC values of greater than 6 but less than 15 cmol (+) kg⁻¹ of soil.

Zeolite which apparently had the lowest initial CEC increased the soil CEC by the smallest margin. Its performance at both ratings was the same. The performance of compost supported the conventional use of organic matter as a temporary CEC improver. However, its effects have been shown to reduce as its levels turn low in soil with decomposition.

Increasing the CEC did not completely prevent, but just reduced the rate of loss of potassium through leaching. Potassium concentration in leachates showed that leaching losses reduced following amendment of soil. Bentonite at a higher rating, recorded the lowest leaching loss. The low leaching loss was due to a high retention capacity, which has been said to increase with soil CEC.

There was an increase in the pH of the soil in all the treatments including the Control. The soil amended with charcoal recorded the highest increases in pH. However, lower pH values were observed at the second observation time (pH2) than at first one (pH1). This was attributed to the

repeated leaching of the basic potassium from soil. An analysis at $P \leq 0.05$ revealed that there was no correlation between soil CEC and soil pH.

Though CEC has been shown to improve plant nutrition, there was no correlation with the dry matter yields of both crops. Both crops suffered nitrogen and phosphorous deficiencies, but no potassium deficiencies were observed in all the treatments.

6.0 RECOMMENDATION

No recommendation has been made owing to the very high application rates of the amendments used in this experiment, which may not be feasible in the field. It can only be suggested that future work to study the effectiveness of the amendments, especially Bentonite when incorporated in fertilisers be conducted.

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APPENDICES

APPENDIX TABLE 1.Experimental layout

5	9	3
7	7	4
8	2	2
6	4	7
9	6	1
2	3	6
4	8	8
1	5	5
3	1	8

1- Control	4 - 25.0g Compost	7 - 12.5g Bentonite
2 - 25g charcoal	5 - 12.5g Compost	8 - 50g Zeolite
3-12.5g charcoal	6 - 25g Bentonite	9 - 25g Zeolite

APPENDIX TABLE 2. Linear correlation coefficients for the association between soil CEC and soil pH or dry matter yield under the different treatments to amend a Mufulira series soil.

	Control	Charcoal 12.5g/kg	Charcoal 25g/kg	Compost 12.5g/kg	Compost 25g/kg	Bent. 12.5g/kg	Bent. 25g/kg	Zeolite 12.5g/kg	Zeolite 25g/kg
pH1	0.79	-0.04	0.80	0.59	-0.47	0.12	-0.84	-0.38	0.29
pH2	0.27	-0.89	0.60	-0.63	0.44	-0.71	0.88	-0.93	0.17
Crop1	0.89	0.02	0.43	0.10	0.67	-0.61	-0.32	0.93	0.71
Crop2	0.90	0.90	0.43	-0.91	0.86	0.44	-0.48	-0.29	0.71
Total	-0.32	-0.64	0.69	-0.84	0.69	0.32	-0.38	0.61	0.71

APPENDIX TABLE 3. Analysis of variance table for soil CEC.

Source of variation	Degree of freedom	Sum of Squares	Mean Square	F- Value	Probability
Replication	2	3.17	1.58	2.90	0.08
Treatment (Factor A)	8	44.80	5.60	10.00	0.00
Error	16	8.54	0.53		
Time (factor B)	2	0.56	0.28	0.38	
AB	16	17.67	1.10	1.49	0.16
Error	36	26.74	0.74		
Total	80	101.47			