Residual Effect of Zeolite on Soil Exchangeable Cations and Cation Exchange Capacity in Sandy Soil Cultivated with Swiss Chard

O. A Sindesi[1], M. N Lewu[2], B Ncube[3], A. Mulidzi[2] and F. B Lewu[1]

***Abstract*—** The increase in global food demand imposes pressure on agricultural soils, leading to soil fertility decline, particularly in African countries. Organic soil conditioners have been used to improve soil fertility although they are not stable and decompose with time. Zeolite is a stable inorganic material that is gaining popularity as a soil conditioner for its ion exchange capacity and high cation exchange capacity (CEC). Zeolites are aluminosilicate minerals, having a negative charge which is balanced by cations. The nature of zeolite in soil needs to be understood as it has a bearing on soil fertility and agricultural potential. A greenhouse pot experiment was conducted at the Agricultural Research Council, Stellenbosch to assess the residual effects of zeolite on soil exchangeable cations (Ca, Na, Mg, and K) and soil CEC. The exchangeability of all soil cations and CEC was increased with zeolite application. Soil exchangeability of Na, Mg, and K in the second growing season was generally reduced ($p<0.05$) on the zeolite-amended treatments, compared to the first growing season. However, the CEC of all treatments was larger in the second season compared to that of the first growing season. The results of this study show that zeolite can be used to improve sandy soil fertility. However, in continuous cropping systems some of the base cations will require replenishment.

***Keywords*—** Cation exchange capacity, exchangeable cations, soil fertility, zeolite

I. Introduction

Global population increase is causing a strain on food security, as a result, there is a growing pressure imposed on agricultural soils [1]. The increased pressure encourages the reduction of soil fertility [2]. Soil fertility decline is a widespread problem especially in African countries [3]. Soil fertility decline has been combated with the use of soil organic conditioners, which provide the soil with some needed nutrients [4]. Soil organic conditioners provide soil aggregation, increased nutrient exchange, moisture retention, and increased water infiltration. However, they are not stable as they decompose with time [5].

With the continuous and increasing pressure on agricultural soils, the development of improved agricultural management strategies directed at improving soil fertility and other agronomical properties is important [1]. Zeolite applications in agriculture as soil conditioners have gained more interest. Zeolite is a stable inorganic material that is used for its ion exchange capacity, it has also been used as a slow-release fertilizer. They can hydrate/dehydrate reversibly without a major change in the structure [6]. Zeolites are aluminosilicate minerals, having a negative charge due to the replacement of Si^{4+} by Al^{3+}. The negative charge is balanced by cations K, Ca, and Na [6] [7].

The nature of zeolite in soil needs to be understood as it has a bearing on soil fertility and agricultural potential. Many studies have recorded improved crop yields, water use efficiency and improved soil nutrient retention. This study assessed the residual effects of zeolite on soil exchangeable cations (Ca, Na, Mg, and K) and soil CEC.

II. Methodology

A. Research Design and Site

A pot experiment was conducted at the Agricultural Research Council, Infruitec-Nietvoorbij, Stellenbosch, South Africa under greenhouse conditions. Swiss chard (Beta vulgaris var. circa cv. Ford Hook Giant) was transplanted and grown on zeolite-amended sandy soil over two growing seasons (2018-2019). There were four soil treatments with six replicates arranged in a randomized complete block design. The treatments were 0% zeolite + 100% sandy soil (Zeolite 0%), 10% zeolite + 90% sandy soil (Zeolite 10%), 20% zeolite + 80% sandy soil (Zeolite 20%), and 30% zeolite + 70% sandy soil (Zeolite 30%).

Urea (46% N): 1.17g/pot, single super phosphate (20% P): 3g/pot, and potassium chloride (50% K): 1.44g/pot were used as base fertilizer. At 4 and 8 weeks after transplanting, 0.33g/pot urea was used as a side dress fertilizer. Throughout the trial, soil moisture was kept between 50 and 75% of pot capacity. Weeds were controlled manually and allowed to decompose in the pot. Insect pests were controlled with Makhro Cyper® (active ingredient: cypermethrin, 200 g L-1) and Mercaptothion® (active ingredient organophosphate 500

O.A Sindesi and F.B Lewu are with [1]Department of Agriculture, Faculty of Applied Sciences, Cape Peninsula University of Technology, Private Bag X8, Wellington 7654, South Africa

M.N Lewu and A.R Mulidzi are with the [2]Soil and Water Science Programme, Agricultural Research Council Infruitec-Nietvoorbij, Private Bag X5026, Stellenbosch 7599, South

B Ncube is with the [3]Centre for Water and Sanitation Research, Faculty of Engineering & the Built Environment, Cape Peninsula University of Technology, Bellville 7535, Cape Town, South Africa

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g·L-1) in the first and second seasons respectively.

B. Data Collection

A standard baseline soil chemical analysis was done before the application of treatments and at the last harvest, for both seasons (Swiss chard had 5 continuous harvests with the last harvest at 143 days after transplanting). Soil exchangeable Ca, Mg, K and Na were extracted using 1.0 N ammonium acetate. The analysis of cation exchange capacity used a method of saturating ammonium acetate at neutral pH. All reagents used for chemical analysis were of analytical grade.

C. Statistical analysis

SAS (version 9.4, SAS Institute Inc., Cary, NC, USA, 2000) software was used to analyse the data for Analysis of Variance (ANOVA). Levene's test was used to determine seasonal homogeneity of variance, following which the findings of both seasons were combined and evaluated in a single overall ANOVA. To look for deviations from normality and insignificant interactions, the Shapiro-Wilk test was used. To compare treatment means, Fisher's least significant difference was determined at the 5% level. A probability level of 5% was considered significant for all tests.

III. RESULTS AND DISCUSSION

A. Baseline soil chemistry and zeolite characteristics

The baseline soil exchangeable cation and cation exchange capacity are presented in Table I. The soil $pH_{(KCl)}$ was 5.4 which was adequate for normal cabbage growth. The zeolite used was granular with a white-to-grey appearance. The zeolite $pH_{(H2O)}$ was relatively high at 8 with a higher CEC of 16. The base cation composition in the used zeolite (in their oxide forms) was 1.3, 2.3, 1.2, and 1.7 % For MgO, Na2O, CaO, and K2O respectively.

TABLE I
BASELINE SOIL CHARACTERISTICS

Characteristic	Value
Exchangeable Cations (cmol/kg)	
Ca	5,83
Na	0,11
Mg	0,39
K	0,12
Cation Exchange Capacity (cmol/kg)	
CEC (pH 7)	5,46

B. Influence of zeolite on soil cation exchange capacity

Cation exchange capacity is a useful indicator of soil fertility as it shows the soil's ability to supply important plant nutrients (K, Mg, and Ca). In this study, soil CEC increased ($p<0.05$) with increased zeolite application (Fig 1). The increase was due to zeolite which acted as an ion exchange site [8]. The increase can also be attributed to the higher CEC of zeolite [9] [10]. The CEC observed at the end of the second growing season was higher compared to that of the first growing season. This shows that the number of negative charges in the soil increase, although the results reported by [5] show a decrease in soil pH at the end of the second growing season. The increase in soil CEC can be attributed to the decrease in soil heavy metal availability (unpublished result).

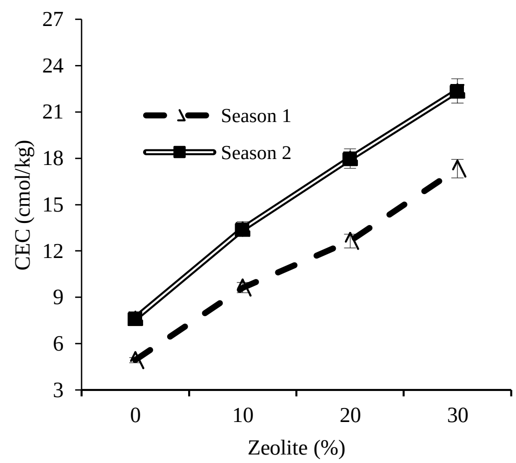


Fig 1 Soil cation exchange capacity response to the application of zeolite

C. Responses of soil exchangeable cation to zeolite application

Soil base cations increased ($p<0.05$) with the increase in zeolite application (Fig 2 and 3). However, there was less soil exchangeable Na, K and Mg in the second season on soils with 20 and 30% zeolite application, except for Ca. Exchangeable Ca generally increased in the second season for all the treatments besides the 30% zeolite treatment. These results conform with the findings of [11] who found more exchangeable K in soil amended with zeolite. Ozbahce et al. (2015) also reported increased availability of Ca, Mg, and K in zeolite-amended soils. The increased exchangeable base cations were due to their presence in the used zeolite [9] [12]. Base cations balance the negative charge of zeolite created by the replacement of Si^{4+} by Al^{3+} [6]. The base cations are replaced by heavy metals when the zeolite is added to soils. This replacement traps heavy metals thereby reducing their availability in soil solutions while increasing the availability of the base cations [8].

The reduced exchangeability of Na, K and Mg cations after the second growing season can be attributed to plant uptake. The reduction can also be attributed to some cations returning into zeolite structures as plants continue to uptake trace elements available in the soil solution [8]. The non-amended treatment did not conform to the trend for exchangeable Mg and K. The exchangeability of these cations increased at the end of the second growing season compared to the first growing season.

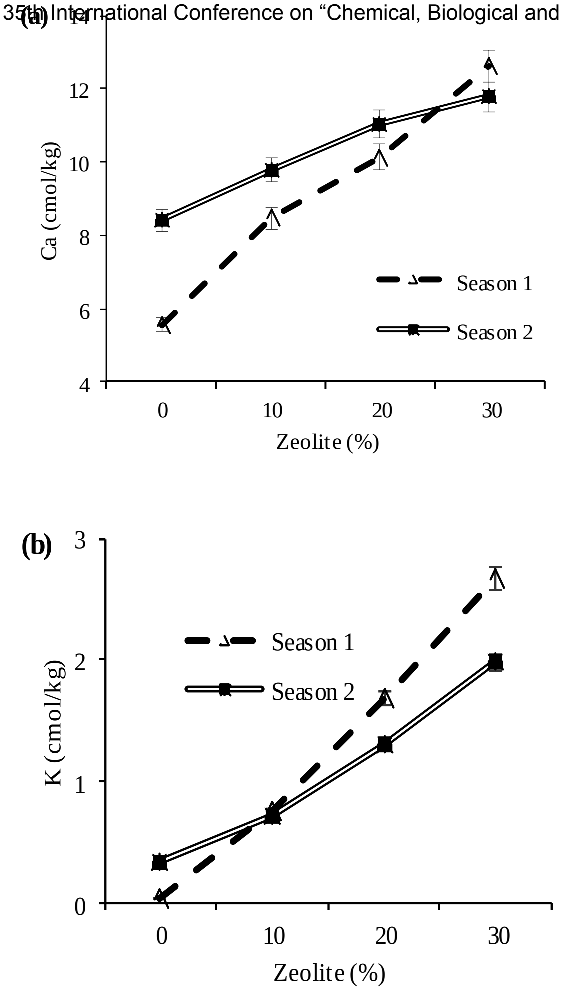
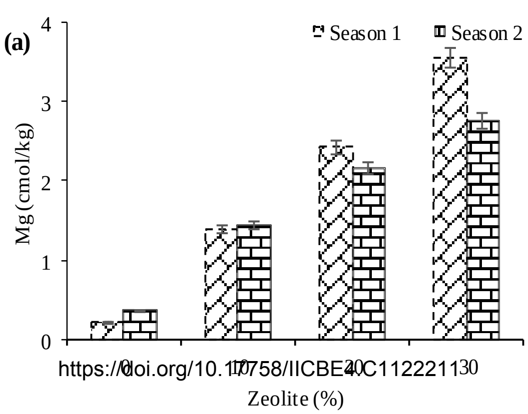


Fig 2 Effect of zeolite on soil exchangeable Ca and K

This increase was in line with the findings of [13] who found an increase in exchangeable Ca and Mg in a long duration of continuous cropping. The increase may be attributed to the decomposition of some plant residues that had been left on the soil after harvesting. Additionally, the increase in the exchangeability of these citations is linked to the increased soil pH reported by [5]. The increased soil pH is linked to Swiss chard's uptake of soil trace elements in the non-amended treatment (unpublished data). This is in line with the findings of [14] who found that deficit irrigation in Swiss chard increased Cd uptake while reducing its availability in the soil. This is constant with the irrigation requirements of this study reported by [5] and proves Swiss chard's potential as a phytoremediation plant.



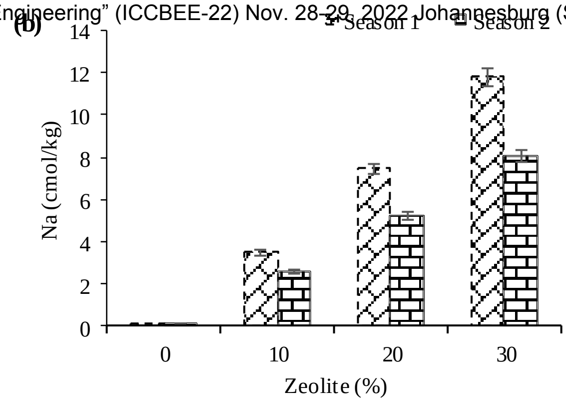


Fig 3 Response of soil exchangeable Mg and Na to zeolite

IV. Conclusion

The result from this study shows that zeolite, through its inherent high CEC, can be used to improve soil exchangeable cations as well as increase the cation exchange capacity of the soil. These are important soil characteristics that can be used as an indication of soil fertility.

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Olwetu A Sindesi obtained his M Agric Degree (Crop production) at the Cape Peninsula University of Technology (CPUT), Wellington, Western Cape, South Africa in 2021. Currently, he is lecturing on Crop Protection at the Department of Agriculture, Cape Peninsula University of Technology. His research focus is on examining the impacts of amendments such as zeolite on soil fertility and soil quality.