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Original Article

Cabbage and Swiss chard yield, irrigation requirement and soil chemical responses in zeolite-amended sandy soil

Olwetu Antonia Sindesi[1], Bongani Ncube[2*], Muinat Nike Lewu[3], Azwimbavhi Reckson Mulidzi[3], Francis Bayo Lewu[1]

[1]Department of Agriculture, Faculty of Applied Sciences, Cape Peninsula University of Technology, Private Bag X8, Wellington 7654, South Africa

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

[3]Soil and Water Science Programme, Agricultural Research Council Infruitec-Nietvoorbij, Private Bag X5026, Stellenbosch 7599, South Africa

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Abstract

Cabbage (*Brassica oleracea* var. *capitata* L.) and Swiss chard (*Beta vulgaris* L. var. *cicla*) are important vegetables for food and nutrition in many parts of the world. Like many other crops, vegetable production is affected by poor soil fertility and shortages of irrigation water. Climate change-related drought has led to shortages of irrigation water in many countries, including South Africa. Farmers have used amendments such as inorganic fertilisers, organic manure, and compost to improve soil fertility. However, organic soil conditioners fall short in providing stable non-decomposable soil amendments, and inorganic fertilisers are expensive. A greenhouse pot experiment was conducted at the Agricultural Research Council Infruitec-Nietvoorbij, Stellenbosch, to assess the effect of zeolite (a soil conditioner) on cabbage and Swiss chard yield, water, and nutrient retention ability of the soil. Zeolite to sandy soil (zeolite: sandy soil) was applied in the ratio of 0:100%, 10:90%, 20:80% and 30:70%. Both cabbage and Swiss chard yields increased, irrigation requirements decreased, and soil acidity was ameliorated due to zeolite application. Cabbage yields were improved by the residual effects of zeolite, while the Swiss chard yield increase was due to vigorous vegetative growth of Swiss chard in zeolite-amended treatments, which led to more N and water utilisation, particularly in the second season. The study also highlighted the potential of zeolite in ameliorating the pH of acidic soils, as well as the water and nutrient-saving ability of zeolite, which are major challenges for crop production in sandy soils. However, there is a need to carry out further studies to find the cost-effective application rates of zeolite under on-farm conditions.

Keywords: Soil nutrients, Leafy vegetables, Sandy soil, Irrigation, Soil conditioner

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**Corresponding author email:*
ncubeb@cput.ac.za

Introduction

Vegetables provide an inexpensive source of energy, nutrients, vitamins, and minerals. In South Africa, the yields of cabbage (*Brassica oleracea* var. *capitata* L.) and Swiss chard (*Beta vulgaris* L. var. *cicla*) are low because of poor soil fertility and water scarcity (Thierfelder et al., 2018). Smallholder and subsistence farming systems generally experience the greatest limitations (Mupangwa et al., 2017). Conservation agriculture is used to address some of the challenges by improving the chemical and physical properties of soil (Mupangwa et al., 2018). Fallowing was traditionally used in agricultural systems in the past to assist in the recovery of nutrients in degraded soils. However, shortages of suitable cropland have prevented its widespread use (Bationo et al., 2007). Fertiliser application is the widely used mean of reversing soil nutrient depletion. However, overuse of mineral fertilizer leads to soil and environmental damage (Bationo et al., 2007). Climate-related drought has also intensified irrigation water shortages, leading to low crop productivity. More water-retentive and nutrient-conserving production practices are needed to reduce crop water requirement (Misra, 2014).

The incorporation of soil conditioning materials such as crop residues, manure and other organic materials can improve soil fertility and structure (Ogunwole et al., 2010). These amendments are easily accessible and used by farmers (Tal, 2018). However, organic amendments are not stable and decompose with time, reducing their effectiveness as amendments for improving the physical properties of soil. Zeolite is a more stable material for improving soil quality and increasing crop productivity (de Campos Bernardi et al., 2013; Aainaa et al., 2018). It is a porous aluminosilicate mineral with high cation exchange capacity and affinity toward ammonium (NH_4^+) and potassium (K^+) cations (Bernardi et al., 2010; Ramesh and Reddy, 2011). Its use as a slow-release carrier of agrochemicals is well documented (Ramesh and Reddy, 2011; Nakhli et al., 2017). The mineral is mined in South Africa but most of the product is exported (Diale et al., 2011).

Plant growth and yield in response to zeolite application have been investigated (Gül et al., 2005; Ramesh and Reddy, 2011; Ramesh et al., 2015). However, information is scarce on the influence of zeolite on the growth of vegetables like Swiss chard and cabbage. The need to investigate the impact of zeolite as a soil conditioner for crops is necessary, given the challenges of soil fertility decline and soil water stress, especially on poor and degraded soils. The objectives of this study were to i) Assess the effect of zeolite on the yield of cabbage and Swiss chard, ii) Evaluate nutrient and water retention in zeolite-amended soils, and iii) Evaluate the performance of cabbage and Swiss chard growing in zeolite-amended soil.

Material and Methods

A pot experiment was conducted in a greenhouse on cabbage (cv. Copenhagen) and Swiss chard (cv. Ford Hook Giant) at the Agricultural Research Council Infruitec-Nietvoorbij, Stellenbosch, South Africa. These varieties were selected because they are commonly planted in South Africa and are readily available. Before the application of treatments, soil samples were collected and analysed to determine the baseline chemical status using accepted standard procedures for soil pH, total available phosphorus (P), ammonium nitrogen (NH_4-N), nitrate-nitrogen (NO_3-N) and potassium (K).

The methods used were the KCl, Bray II, Kjeldahl method, ICP-OES and the Tetraphenylboron, respectively. The treatments were applied at the ratios of 0:1, 1:9, 2:8 and 3:7 zeolite to sandy soil (kg) in a randomized complete block design with six replicates. Each pot had a total of 12kg of soil and a mixture of soil and zeolite. The fertiliser used on the plants was urea (46% N), single-super phosphate (20% P) and potassium chloride (50% K). Fertilizers were applied at the rate of 1.17g/pot N and 3g/pot P for both cabbage and Swiss chard respectively, while 1.92g/pot K and 1.44 K were applied to cabbage and Swiss chard respectively. Six-week-old seedlings produced at Western Cape Seedlings, a commercial plant nursery were transplanted in 30 cm plastic pots, planting one seedling in each pot. Cabbage received an additional side-dressing of urea at 1.11 g/pot at 3 and 6 weeks after transplanting (WAT), while Swiss chard received 0.33 g/pot at 4 and 8 WAT. Before the commencement of irrigation, the soil water content was determined gravimetrically. Thereafter, all treatments were irrigated to pot capacity (PC) before planting. Monitoring of soil water content was done through the gravimetric method and pot weighing. Soil moisture was maintained between 50-70 % PC throughout the study and the amount of irrigation applied was properly recorded.

The experiment was carried out over two growing seasons. The first season was from late autumn to late spring 2018 for the two crops; the second season was early autumn to early spring 2019 for Swiss chard and early winter to late spring 2019 for cabbage. Hand weeding was employed for weed control while Makhro Cyper® (active ingredient: cypermethrin, 200 g L^{-1}) and Mercaptothion® (active ingredient organophosphate 500 gL^{-1}) were used in rotation for pest control in the first and second seasons respectively (Sindesi et al., 2021).

Cabbage was harvested 133 days after transplanting (DAT). Non-wrapper leaves surrounding the head were detached and the remaining head was chopped into thin slices, and then dried in the oven at 70°C till constant weight. For Swiss chard, mature leaves, with a length ≥15 cm measured from the leaf apex to the base of the stalk were harvested. The first harvest for Swiss chard was at 59 DAT and subsequently after every 21 days. There were 5 harvests in total. After each harvest, leaves were dried in the same manner as the cabbage. The total dry yield for Swiss chard was the sum of the 5 yields. The soil was sampled for chemical analysis at the end of every growing season. Analysis of variance (ANOVA) was performed on data according to season, using the SAS statistical software (ver. 9.4, SAS Institute Inc., Cary, NC). Results of the two seasons were investigated in one overall ANOVA after testing for season homogeneity of variance using Levene's test. The Shapiro-Wilk test was carried out to test for deviation from normality and insignificant interactions. Fisher's least significant difference was employed when comparing treatment means of non-significant interactions.

Results and Discussion

Cabbage dry matter yield in response to Zeolite application

Dry matter (DM) content can be used as an indicator of the organic matter accumulation in leafy vegetables. In seasons 1 and 2 of this study, there was a general increase in the DM yield of cabbage with an increase in zeolite rate (Fig. 1, Table 2), except for the 30% zeolite treatment, which had a significant drop in yield ($p \leq 0.05$) compared with the other zeolite-amended treatments (season 2). However, the second season had higher yields compared to season 1 ($p \leq 0.05$). The application of zeolite generally increased DM yield and improved soil pH. (season 1) (Fig. 3 & Fig. 5a). Additionally, the application of zeolite encouraged continuous nitrogen (N) availability, as it adsorbed and retained N in the plant root zone, thus allowing a gradual slow release of this nutrient. The observed effect of zeolite on the DM yields was similar to the findings of Aainaa et al. (2018) who found that lettuce (*Lactuca sativa*) DM yield increased when cultivated in soils amended with zeolite. Zeolite application to soils along with N fertiliser has been shown to reduce N leaching, reduce volatilization, slow down the mineralization process and retard nitrogen release into soil solutions (Mondal et al., 2021). The retarded nitrogen release by zeolite paves the way for a more gradual and continuous slow release of nitrogen to the plant root zone throughout the growing season, thereby increasing N use efficiency and leading to increased crop yields (Méndez Argüello et al., 2018).

Table-1. Zeolite and baseline soil characteristics.

Zeolite physical properties	**Description**
Colour	White to grey
Appearance	Granules
pH (30 g in 60 mL water)	8
Cation exchange capacity ($mg \cdot kg^{-1}$)	16
Water adsorption (on sinter plate)	400%
Zeolite chemical property	(%) Typical
SiO_2	64.3
Al_2O_3	12.7
TiO_2	0.1
MgO	1.3
Na_2O	2.3
Fe_2O_3	1.3
CaO	1.2
K_2O	1.7
Loss on ignition	8.4
Zeolite mineralogy	Approximate
% Clinoptilolite	>90
% Quartz	<5
Baseline soil properties	Value ($mg \cdot kg^{-1}$)
NH_4-N	7.11
NO_3-N	32.76
P (BRAY II)	47.00
K	47.00
$pH_{(KCl)}$	5.40

Table-2. P-values for the combined ANOVA on seasons for cabbage

Source	df	H[a]	Irrigation	pH	K	NO_3^-N	P Bray II	NH_4^-N
Season (S)	1	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Season (Rep)	10	0.4127	0.1079	<0.0001	0.3089	0.0009	0.0428	0.0008
Treatment (T)	3	<0.0001	<0.0001	<0.0001	<0.0001	0.7863	<0.0001	<0.0001
T × S	3	0.0012	<0.0001	<0.0001	<0.0001	0.6853	<0.0001	0.0002

H[a] = Head dry yield.

The reason for blocking was to control possible position effects. If the block effect is significant, then it indicates that blocking was necessary and effective.

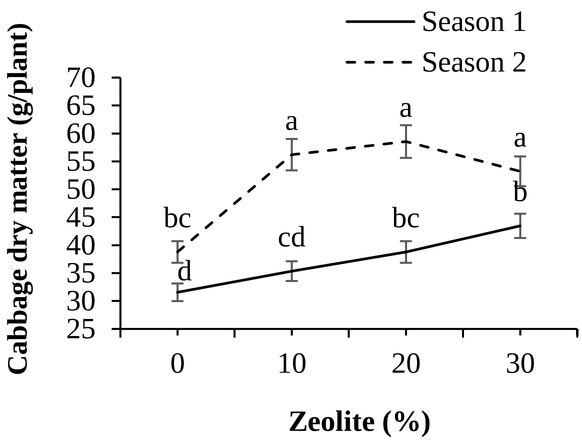

Fig 1. Effect of zeolite application on dry matter yield of cabbage. Bars with the same letter are not significantly different, LSD (P=0.05) = 5.41.

DM yield of heads of cabbage (31.56 to 58.55 g/head) in this trial was higher than those (4.4 to 28 g/head) reported by Olaniyi and Ojetayo (2011), even though the same Copenhagen cultivar was used in both studies. The differences in the DM yields can be attributed to differences in the growing season and production management practices (Torkashvand and Shadparvar, 2013)

Swiss chard dry matter yield in response to Zeolite application

The total DM yield of Swiss chard was significantly higher (p≤0.05) in zeolite-amended treatments as compared to non-amended soils in both seasons (Fig. 2, Table 3).

Swiss chard dry mass obtained in the first growing season was comparable to the findings of Maboko et al. (2017) with DM yield ranging from 32 to 50 g/plant. However, the second season yield reduced significantly (p≤0.05) when compared to the first season harvests. The variation in yield may be due to the slight difference in the growing season. The increase in DM yields due to zeolite application may be attributed to the ability of zeolite to sorb and slowly release nutrients and moisture to plants during the growth period. This trend was also observed in cabbage head DM yield. The findings of this study may be associated with the general improvement in soil quality (improved soil pH and water-retaining ability of zeolite) (Bernardi et al., 2010; Ramesh and Reddy, 2011; Torkashvand and Shadparvar, 2013; Lee et al., 2019).

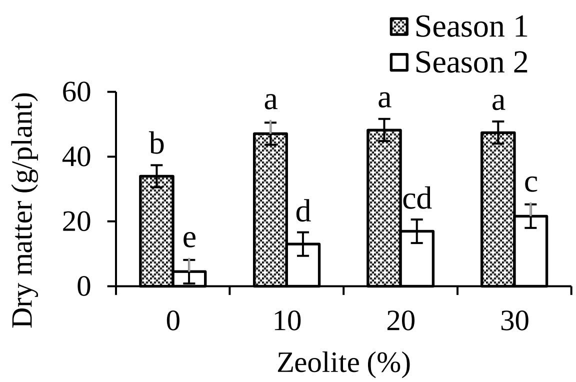

Fig-2. Effect of zeolite on the total seasonal dry matter yield of Swiss chard. Bars with the same letter are not significantly different, LSD (P=0.05) = 14.39.

Influence of zeolite on the irrigation water requirement of cabbage

In the first growing season, the water requirement of cabbage generally decreased with increasing application of zeolite (Fig. 3), while in the following growing season, the water requirement of cabbage grown in the zeolite-amended soil (10 and 20% zeolite treatments) significantly exceeded that of the control treatment (p≤0.05).

There was a significant (p≤0.05) decrease in irrigation water across treatments and seasons (Table 2). The total irrigation applied to cabbage was greater than the 192 to 301 mm/plant obtained in a field study conducted by Beshir (2017) for different cabbage varieties.

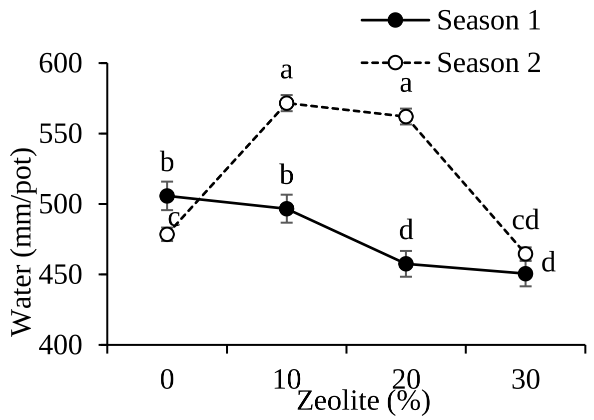

Fig-3. Water demand of cabbage in response to the application of zeolite. Bars with the same letter are not significantly different, LSD (P=0.05) = 16.21.

The length of the growing season, season differences, cabbage variety, and the production management practices are some of the factors that are responsible for these variations (Roux et al., 2016; Beshir, 2017). Additionally, the effect of zeolite on total cabbage water demand was similar to the observations made by Ramesh et al. (2015) and Torkashvand and Shadparvar (2013). At higher rates of zeolite, more soil moisture was retained, through increased aggregate adhesion, thereby, reducing irrigation needs (Torkashvand and Shadparvar, 2013).

In the first season, the non-amended treatment required more irrigation as compared to the zeolite-amended treatments but had the least DM yield due to poor water holding capacity (Fig. 1). All plant metabolic activities are facilitated by water; these processes are critical in plant growth and development which leads to the final yields (Robbins and Dinneny, 2018). Part of the metabolic processes requires the use of water for transpiration and transport of nutrients from the soil to green plant tissues, including the use of water for the process of photosynthesis (Kapoor et al., 2020). Plant nutrients from the soil, including soil moisture, are crucial and influence final crop yields, especially in leafy vegetables. The results of total water requirement and dry matter yield (Fig. 3 & Fig. 1) in this study indicate that there was limited metabolic activity in cabbage grown in the control treatment, during the first growing season, compared to the cabbage grown in the zeolite-amended soils. The results further suggest that there was a greater water use efficiency (yield produced/ water used) with higher levels of zeolite application than the control treatment in both seasons.

Influence of zeolite on the irrigation water requirement of Swiss chard

Each season, the total irrigation water use in the non-amended treatment was significantly lower ($p \leq 0.05$) as compared to the zeolite-amended soils (Fig. 4). However, the irrigation amounts were not significantly different across season replications and there was no interaction between treatments and the seasons (Table 3).

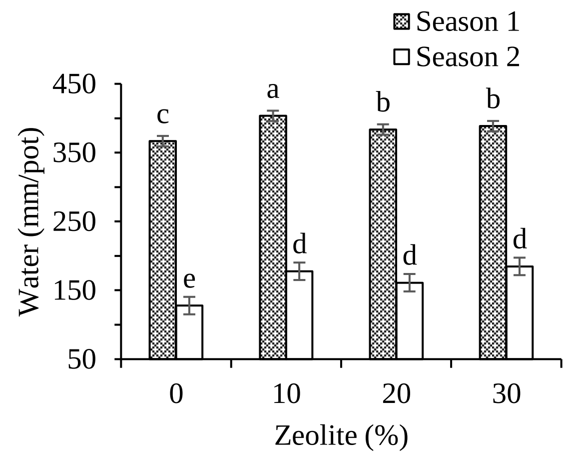

Fig-4. Effect of zeolite on Swiss chard seasonal irrigation. Bars with the same letter are not significantly different, LSD (P=0.05) = 27.36.

In the first season, Swiss chard water application ranged between 366 and 403 mm/plant, which was comparable with the 390 mm/plant requirement reported by Mhlauli (2000). The least amount of water utilised by the 0 % zeolite treatment in the two seasons may be attributed to the overall slow growth observed in the treatment, unlike the zeolite-amended treatments with vigorous growth and higher yields. Vigorous growth is linked to higher evapotranspiration rates and other plant metabolic activities, and that led to higher water demand for Swiss chard grown on zeolite amended soil (Daiss et al., 2008). The vigorous growth resulted in higher DM yield (Fig. 2) obtained for Swiss chard grown in zeolite-amended soils. This may be linked to the ability of zeolite to improve the uptake of water by plants and the improved soil properties such as soil pH. Improved water uptake increases the rate of metabolic activity. It is partly due to fewer forces holding water in the soil as well as increased pore size and water holding channels, created by increased aggregate adhesion, due to increased zeolite application (Torkashvand and Shadparvar, 2013).

Soil chemical response to zeolite application

The initial soil chemical fertility status was favourable for normal plant growth (Table 1). The clinoptilolite zeolite was alkaline (pH 8) in nature (Table 1) and significantly ($p \leq 0.05$) increased soil pH (Fig. 5, Table 2 & Table 3) in soils planted with both cabbage and Swiss chard. The increase in soil pH is due to the alkalinity and the negative charges of zeolite, which allowed the sorption of cation (Aainaa et al., 2018).

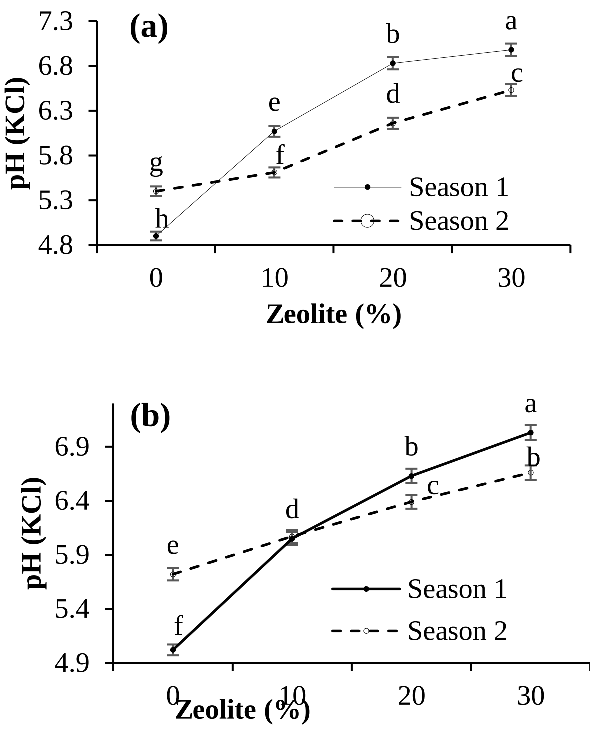

Fig-5 (a & b). Effect of zeolite on the pH of the potting soil of (a) cabbage and (b) Swiss chard at the end of each season. Bars with the same letter are not significantly different, LSD (P=0.05) = (a) 0.07 and (b) 0.06.

The non-amended treatments remained close to the baseline soil pH (Fig. 5), demonstrating the ability of zeolite to act as liming agent in soils, which was also observed by Ramesh and Reddy (2011). After the second growing season, soil pH generally had a slight decrease compared to the first growing season. This was probably due to further application of urea (46% N) fertiliser, and carbon removal in the form of yield, which relates to the N and C cycles respectively (Zhang et al., 2019). Ammonium-based nitrogen fertilisers increase the concentration of hydrogen ions in the soil when ammonium nitrogen is converted to nitrate. Urea, used in this study, is an ammonium-based fertiliser and its application to soils contributed to the N cycle, which assisted in decreasing soil pH in the second season. Additionally, the harvesting of leafy vegetables is linked to exported alkalinity, which relates to the removal of carbon from the soil, resulting in increased hydrogen ions (Bleam, 2016).

There was a linear increase in K^+ cations with increased application of zeolite in the soils amended with zeolite for both cabbage and Swiss chard (Fig. 6 & Fig. 7). A significant interaction was observed between season and treatment for the increase in K ion concentration. However, no significant difference ($p \geq 0.05$) was observed among seasonal replications for both crops. The K^+ increase in response to zeolite application in this study may be associated with the K_2O content in the applied zeolite as well as the affinity of zeolites to K^+ (de Campos Bernardi et al., 2013). The cavities or porous matrix and cation exchange capacity (CEC) of zeolite protect NH_4^+ and K^+ cations due to large pores, which permit adsorption of cations but are not large enough to permit entry of nitrifying bacteria (Ramesh and Reddy, 2011). It is because zeolite adsorbs cations from chemical fertilisers, reduces leaching and allows the slow release of nutrients to plants (Abdi et al., 2006).

Table-3. P-values for the combined ANOVA on seasons for Swiss chard

Source	df	Dry Yield	Irrigation	pH	K	NO_3^-N	P Bray II	NH_4^-N
Season (S)	1	<0.0001	<0.0001	0.0044	<0.0001	0.0006	<0.0001	<0.0001
Season (Rep)	10	0.4911	0.2239	0.006	0.3363	0.1067	0.2311	0.0066
Treatment (T)	3	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
T × S	3	0.1136	0.145	<0.0001	<0.0001	<0.0001	0.6893	<0.0001

In this study, soil P availability decreased with zeolite application and with the season (Fig. 6 & Fig. 7) for both cabbage and Swiss chard. The decrease in P was significant ($p \leq 0.05$) across treatments, season, season replications, and in the interaction between season and treatment for soils grown with cabbage. However, in Swiss chard cultivated soils, the decrease was significant across the treatments and seasons only. This decrease did not affect the dry matter yields of both vegetables.

The results of soil P contrast with the findings by Abdi et al. (2006) who found that minerals N, P and K all increased in the soil with zeolite application. The decreasing P with increased zeolite rate in this study may be due to higher plant uptake. Phosphorus does not adsorb into zeolite channels to allow slow nutrient release (Abdi et al., 2006). Hypothetically, increased P uptake from soil to plants can be improved by moving reactive products such as Ca^{2+} and $H_2PO_4^-$ into zeolites exchangeable sites, which then provide a sink for the removal of the reactive products (Aainaa et al., 2018). Without this process, P becomes readily available for plant uptake and in field production systems, this availability may subject P to leaching (Erickson et al., 2005).

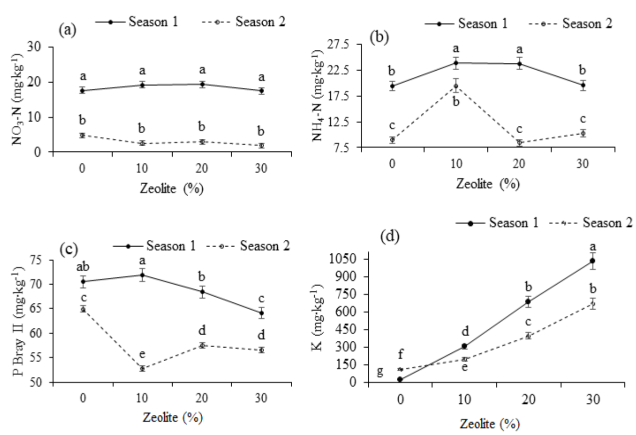

Fig-6 (a-d). Chemical status of cabbage potting soil in response to the applied zeolite. Bars with the same letter are not significantly different, LSD (P=0.05) = (a) 5.04 (b) 3.14 (c) 2.22 (d) 57.49.

The behaviour of the two types of soil mineral N (NH_4^-N and NO_3^-N) in this study revealed that there may be a threshold application rate for zeolite to get benefits from N. At the end of the first season, the amount of NH_4^-N and NO_3^-N in the soil was almost similar in the 30 % and the 0 % zeolite treatments (Fig. 6 & Fig. 7). There was a significant ($p \leq 0.05$) decrease in NH_4^-N across treatments, season, season replications, and in the interaction between season and treatment in both cabbage and Swiss chard soils (Table 2 & Table 3). As explained by Ramesh et al. (2015), the adsorption of NH_4^-N into zeolites cavities decreases soil N losses, thereby ensuring its gradual release directly to plant roots and decreasing the problems of leaching. The phenomenon reduces plant growth in the initial growth phases, as N is held by strong bonds in the cavities which reduces plants' ability to assimilate it. Usually, there is little available soil N remaining in the soil at the end of a growing season due to crop uptake. This proved to be true as the results of this study confirmed a reduction in NO_3^-N availability. Both cabbage and Swiss chard soils showed a reduction in NO_3^-N at the end of each season compared to the baseline soil NO_3^-N of 32.76 mg kg^{-1}. However, NH_4^-N levels increased from the initial level of 7.11 mg kg^{-1} and this may be partly linked to the application of urea [CO $(NH_2)_2$]. Urea is convertible into NH_3 or NH_4 by the enzyme urease, which increases the NH_4^-N content of the soils. This is more likely than being due to zeolite affinity towards NH_4^-N (Abdi et al., 2006; de Campos Bernardi et al., 2013; Aainaa et al., 2018). The reduction of NO_3^-N in the soils of both crops may be due to the high assimilation of the mineral by plants, especially during the second growing season of this study, where the lowest amounts of NO_3^-N were recorded under 30 % zeolite. The tendency of the non-amended treatments to have high plant-available NO_3-N after the second growing season ended could be due to retarded plant growth, hence reduced plant uptake.

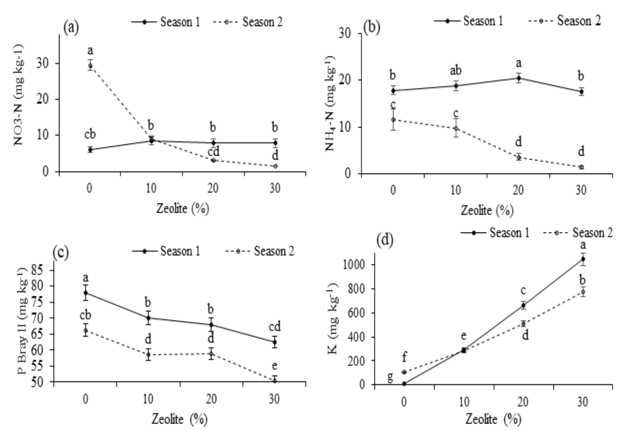

Figure-7 (a-d). Effect of zeolite on the chemical status of Swiss chard potting soils at the end of each season. Bars with the same letter are not significantly different, LSD (P=0.05) = (a) 3.37 (b) 2.57 (c) 4.05 (d) 55.50.

Conclusion

The study highlighted the liming potential of zeolite and further showed that increased zeolite application increases affinity towards K. The first season observations also showed that there might be a threshold limit to the application rate of zeolite for N availability to plants. Water requirement and yield responses to zeolite application were dependent on crop species and the residual effect of zeolite in subsequent seasons. Zeolite improved Swiss chard yields throughout the study although the cabbage yields were more improved with the residual effects of zeolite. The improved Swiss chard yields were linked to vigorous crop growth, which led to more N and water utilisation, particularly in the second season, in zeolite-amended treatments. The results showed great potential for zeolite in saving water and reducing crop nutrient requirements. However, there is a need to carry out further studies to find the cost-effective application rates of zeolite under field conditions as well as to establish the threshold limits.

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References

Aainaa HN, Ahmed OH and Ab Majid NM, 2018. Effects of clinoptilolite zeolite on phosphorus dynamics and yield of *Zea mays* L. cultivated on an acid soil. Public Library of Science One. 13(9): e0204401.

Abdi GH, Khosh-Khui M and Eshghi S, 2006. Effects of natural zeolite on growth and flowering of strawberry (*Fragaria ananassa Duch*.). Int. J. Agric. Res. 1(4): 384-389.

Bationo A, Kihara J, Vanlauwe B, Waswa BS and Kimetu J, 2007. Soil organic carbon dynamics, functions and management in West African agro-ecosystems. Agr. Syst. 94(1):13-25.

Bernardi AC, Monte MBDM, Paiva PRP, Werneck CG, Haim PG and Barros FDS, 2010. Dry matter production and nutrient accumulation after successive crops of lettuce, tomato, rice, and andropogongrass in a substrate with zeolite. Revista Brasileira de Ciência do Solo. 34: 435-442.

Beshir S, 2017. Review on estimation of crop water requirement, irrigation frequency and water use efficiency of cabbage production. J. Geosci. Environ. Protect. 5(7): 59-69.

Bleam WF, 2016. Soil and environmental chemistry. Academic Press.

Daiss N, Lono GM, Socorro AR, Bruckner U, Heller J and Gonzalez M, 2008. The effect of three organic pre-harvest treatment on Swiss chard (*Beta vulgaris* L. var. *cycla* L.) quality. Eur. Food Res. Tech. 226: 345-353.

de Campos Bernardi AC, Oliviera PPA, de Melo Monte MB and Souza-Barros F, 2013. Brazilian sedimentary zeolite use in agriculture. Microporous and Mesoporous Materials. 167: 16-21.

Diale PP, Muzenda E and Zimba J, 2011. A study of South African natural zeolite properties and applications, pp 698–703. In Proceedings, World Congress on Engineering and Computer Science, 19-21 October 2011, WCECS 2, San Francisco, CA.

Erickson JE, Cisar JL, Snyder GH and Volin JC, 2005. Phosphorus and potassium leaching under contrasting residential landscape models established on a sandy soil. Crop Sci. 45(2): 546-552.

Gül A, Eroğul D and Ongun AR, 2005. Comparison of the use of zeolite and perlite as substrate for crisp-head lettuce. Sci. Hortic. 106(4): 464-471.

Kapoor D, Bhardwaj S, Landi M, Sharma A, Ramakrishnan M and Sharma A, 2020. The impact of drought in plant metabolism: how to exploit tolerance mechanisms to increase crop production. Appl. Sci. 10(16): 5692.

Lee DS, Lim S, Park HJ, Yang HI, Park SI, Kwak JH and Choi WJ, 2019. Fly ash and zeolite decrease metal uptake but do not improve rice growth in paddy soils contaminated with Cu and Zn. Environ. Int. 129: 551-564.

Maboko MM, Du Plooy CP, Sithole MP and Mbave A, 2017. Swiss chard (*Beta vulgaris* L.) Water use efficiency and yield under organic and inorganic mulch application. J. Agric. Sci. Tech. 19:1345-1354.

Méndez Argüello B, Vera Reyes I, Cárdenas Flores A, Santos Villarreal G, Ibarra Jiménez L and Lira Saldivar RH, 2018. Water holding capacity of substrates containing zeolite and its effect on growth, biomass production and chlorophyll content of Solanum lycopersicum Mill. Nova Scientia. 10(21): 45-60.

Mhlauli NC, 2000. Growth analyses and soil water balance of selected vegetable crops. M.S. thesis. Horticultural Science Department, University of Pretoria, Pretoria, South Africa.

Misra AK, 2014. Climate change and challenges of water and food security. Int. J. Sustain. Built Environ. 3(1): 153-165.

Mondal M, Biswas B, Garai S, Sarkar S, Banerjee H, Brahmachari K, Bandyopadhyay PK, Maitra S, Brestic M, Skalicky M and Ondrisik P, 2021. Zeolites Enhance Soil Health, Crop Productivity and Environmental Safety. Agron. 11(3): 448.

Mupangwa W, Mutenje M, Thierfelder C and Nyagumbo I, 2017. Are conservation agriculture (CA) systems productive and profitable options for smallholder farmers in different agro-ecoregions of Zimbabwe? Renew. Agr. Food Syst. 32(1): 87-103.

Mupangwa W, Nyagumbo I, Mutsamba E, Mhlanga B and Mataruse J, 2018 Maize responses to reduced tillage, different plant residue mulch and nitrogen fertiliser on granitic sandy soils of Zimbabwe. S. Afr. J. Plant Soil. 35(5): 1-10.

Nakhli SAA, Delkash M, Bakhshayesh M and Kazemian H, 2017. Application of zeolites for sustainable agriculture: a review on water and nutrient retention. Water Air Soil Pollut. 12: 464.

Ogunwole JO, Iwuafor ENO, Eche NM and Diels J, 2010. Effects of organic and inorganic soil amendments on soil physical and chemical properties in a West Africa Savana agroecosystem. Trop. Subtrop. Agroecosystems. 12(2): 247-255.

Olaniyi JO and Ojetayo AE, 2011. Effect of fertilizer type on the growth and yield of two cabbage varieties. J. Anim. Plant Sci. 12(2): 1573-1582.

Ramesh K and Reddy DD, 2011. Zeolites and their potential uses in agriculture: D.L Sparks. Advances in agronomy. Elsevier Science and Technology, Newark, DE. 113: 219-241.

Ramesh V, Jyothi JS and Shibli SMA, 2015. Effect of zeolites on soil quality, plant growth and nutrient uptake efficiency in sweet potato (*Ipomoea batatas* L.). *J. Root Crops*. 41(1): 25-31.

Robbins NE and Dinneny JR, 2018. Growth is required for perception of water availability to pattern root branches in plants. Proceedings National Academy of Sciences of the United States of America. 2018. 115(4): E822-E831.

Roux B, Van der Laan M, Vahrmeijer T, Annandale J and Bristow K, 2016. Estimating water footprints of vegetable crops: Influence of growing season, solar radiation data and functional unit. Water. 8: 473.

Sindesi OA, Lewu MN, Ncube B, Mulidzi R and Lewu FB, 2021. Mineral composition of potted cabbage (Brassica Oleracea Var. Capitata L.) grown in zeolite amended sandy soil. Agriculture (Pol'nohospodárstvo). 67(3):103-112.

Tal A, 2018. Making conventional agriculture environmentally friendly: Moving beyond the glorification of organic agriculture and the demonization of conventional agriculture. Sustain. 10(4): 1078.

Thierfelder C, Baudron F, Setimela P, Nyagumbo L, Mupangwa W, Mhlanga B, Lee N and Gérard B, 2018. Complementary practices supporting conservation agriculture in Southern Africa. A review. Agron. Sustain. Dev. 38(2): 16.

Torkashvand AM and Shadparvar V, 2013. Effect of some organic waste and zeolite on water holding capacity and PWP delay of soil. Curr. Biot. 6(4): 459-465.

Zhang YY, Wu W and Liu H, 2019. Factors affecting variations of soil pH in different horizons in hilly regions. Public Library of Science One. 2019: 14(6): e0218563.

Contribution of Authors

Sindesi OA: Conducted experiments, collected data, and wrote the first draft of the manuscript.
Ncube B: Supervised the work, helped with the write-up, editing and proofreading of the manuscript.
Lewu MN: Conceived idea, designed the research and helped in data analysis, write-up and editing of the manuscript, NRF grant holder of the research.
Mulidzi AR: Part of the research team, co-supervised the student and edited the manuscript.
Lewu FB: Conceived idea, part of the research team, co-supervised the student and edited manuscript.