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RESEARCH ARTICLE

GROWTH AND FRESH YIELD RESPONSE OF SWISS CHARD (*BETA VULGARIS* L. VAR. *CICLA*) CV. FORD HOOK GIANT TO ZEOLITE SOIL AMENDMENT

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ABSTRACT

Vegetable and other crop producers face numerous challenges, including high input costs, water shortages, and soil degradation. Zeolite, a microporous aluminosilicate mineral with high cation exchange capacity and water retention properties, is receiving a growing research interest due to its positive effects as a soil amendment on various crops, including vegetables, however, specific studies on its impact on Swiss chard are relatively limited. This study investigated the effects of zeolite application on the growth and yield of Swiss chard (Beta vulgaris L. var. cicla) cv. Ford Hook Giant under greenhouse conditions over two growing seasons (2018 and 2019). Zeolite was applied at weight-to-weight ratios of 0:10, 1:9, 2:8, and 3:7 to sandy soil. Growth parameters (plant height, leaf area, and chlorophyll content) were monitored weekly, and fresh and dry yields were measured at 59 days after transplanting. Results indicated that zeolite application improved ($p \leq 0.05$) leaf area, leaf number, fresh and dry yield in the second growing season, including their growth rate per week. These improvements were linked to improved soil quality due to zeolite application. The initial season exhibited inconsistent trends, likely due to the integration period required for zeolite to stabilise in the soil system. Swiss chard leaf moisture also reduced ($p \leq 0.05$) with increased zeolite application in the second season, this was linked to Swiss chard cultivated under the zeolite-amended treatments having higher leaf growth which may have encouraged greater transpiration losses. Furthermore, chlorophyll content index and leaf moisture percentage showed limited direct correlation with yield, suggesting that growth parameters such as plant height and leaf area are better indicators of yield potential in Swiss chard. These findings demonstrate zeolite's potential to enhance vegetable production, emphasising the need for a stabilisation period in sandy soils. Future research should explore the long-term effects of zeolite application on crop performance and soil health.

KEYWORDS

Zeolite, Swiss chard, sandy soil, growth parameters, fresh yield, soil amendment.

1. INTRODUCTION

Vegetables are essential for health and nutritional benefits in the human diet (Sharma et al. 2021; Noopur et al. 2023). Vegetables supply large amounts of minerals, vitamins, carbohydrates, proteins, dietary fibre and various nutraceutical compounds (Sharma et al., 2021). They are also the cheapest source of protection against various diseases (Kumar et al., 2020). According to, there is an inverse relationship between high vegetable consumption and disease (Noopur et al., 2023). In developing countries, vegetables play an essential role in managing malnutrition, particularly the ones that are easy to cultivate. Swiss chard (*Beta vulgaris* L., *var. cicla*) is one of the vegetables that has gained significant interest from farmers due to its ease of cultivation and adaptability to diverse environmental conditions (Franzoni et al. 2024; Ojiewo et al., 2015). Swiss chard is a biennial herbaceous leafy vegetable with nutraceutical properties, and it is one of the most widely consumed leafy vegetables in South Africa (Dumani et al. 2021).

In South Africa, vegetable and other crop producers face numerous challenges, including high input costs, water shortages, and soil degradation (Lötter et al., 2009; Chikozho et al., 2020). Farmers have used organic manures, such as compost and animal manure, to combat high input costs, water shortages, and soil degradation (Atoloye, 2024). However, organic manures are not stable and easily decomposable; they are also bulky and may introduce weed seeds to the farmers' fields, leading to increased labour requirements (Gamage et al., 2023; Mwangi et al., 2024). Therefore, there is a need to find more stable and innovative soil amendments to reduce farm input costs and ameliorate soil degradation while improving crop yields.

Zeolite is a relatively cheap soil amendment which can be used as an alternative to natural organic amendments (Javaid et al., 2024). Zeolite has been observed to improve soil quality and increase soil moisture holding capacity (Ibrahim et al. 2021; Sindesi et al. 2023a). Zeolites are natural inorganic amendments; they are stable materials that improve soil quality and increase crop productivity (Nur Aainaa et al., 2018; Sindesi et al., 2023b). Zeolites are a group of microporous crystalline aluminosilicate minerals of alkaline nature, with large surface area and ion exchange capacity and a great affinity towards ammonium (NH_4^+) and potassium (K^+) cations (Gül et al. 2005; Ramesh and Reddy, 2011). Due to its benefits and properties, zeolite has gained popularity as a soil amendment. There is also growing research on the positive effects of zeolite as a soil

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amendment on various crops, including vegetables. However, specific studies it's the impact on Swiss chard are relatively limited. Nevertheless, based on its known properties of improving soil quality, water retention, and nutrient availability, zeolite has the potential to enhance the growth and yield of Swiss chard and other vegetable crops. This study examined the influence of zeolite on Swiss chard growth and yield over 8 weeks after transplanting.

2. Material and Methods

2.1 Research Design

A greenhouse study was conducted at the Agricultural Research Council, Infruitec-Nietvoorbij, Stellenbosch, South Africa (33.914476° S and 18.861322° E) using Swiss chard (Beta vulgaris var. circa cv. Ford Hook Giant). The study was conducted over two growing seasons: late autumn to late spring 2018 and early autumn to early spring 2019. The study assessed the effects of zeolite as a soil amendment on Swiss chard growth rate and Swiss chard fresh yield. Zeolite to sandy soil application was based on weight-to-weight ratios of 0:10, 1:9, 2:8, and 3:7. Each planting pot had 12 kg of soil or soil and zeolite mixture, and the pots were arranged in a randomised complete block design, with six (6) replications. The zeolite used was of clinoptilolite mineralogy composed of 64.30% silicate ($SiO2$) and 12.70% aluminium oxide ($Al2O2$). Details about the initial soil chemical characteristics and other characteristics of the zeolite used in this study are reported in the work of Sindesi et al. (2023). The fertiliser applications on each pot are described in the work by Sindesi et al. (2022). Six-week-old Swiss chard plants of about 7 cm were used for the experiment. One plant was transplanted into each pot.

2.2 Data Collection

Growth parameter data was collected four weeks after the transplanting of the seedlings and continued weekly over four consecutive weeks. Swiss chard growth was represented by the number of loose leaves per plant, plant height, leaf width, leaf chlorophyll content index (CCI), and leaf length. Fresh yield was collected 59 days after transplanting.

2.2.1 Number of loose leaves per plant

All the true leaves, fully developed leaves with a petiole or white stalk and a blade that were adequately grown and observed to have moved away from the main growing point, were counted and recorded.

2.2.2 Plant height

Plant height was measured using a transparent ruler, and care was taken to ensure that the ruler was vertically placed next to the plant, with the ruler's zero end positioned at the plant's base, where the stem met the soil. Only the tallest leaf was observed on each plant.

2.2.3 Leaf area

The leaf width (maximum value perpendicular to the midrib) and the leaf length (maximum value along the midrib) were measured and recorded to calculate the leaf area. These parameters were further used to develop ratio and regression estimators to calculate the leaf area. The formula for the Swiss chard leaf area entailed finding the slope of the leaf length and leaf width (linear regression), the Y was represented by leaf width, while the X was represented by leaf length. After finding the slope, it (the slope) was multiplied by the leaf length and the leaf width.

LEAF AREA ≈ m * L * W

W was the leaf width

L was the leaf length

m was the slope of the line

2.2.4 Leaf Chlorophyll content index

Leaf chlorophyll content index (CCI) data was collected from the top edge of the largest leaf on each plant using a CCM-200 plus chlorophyll content meter, manufactured by Opti-Sciences, USA.

2.2.5 Growth rates

The growth rates of the observed parameters were calculated by dividing the difference between the values recorded in the first and fourth weeks by 3.

2.2.6 Fresh yield

Swiss chard was harvested 59 days after transplanting by cutting the stalks at the base of the plants, and the fresh weight (grams/3 plant) was measured immediately using a weighing scale. Swiss chard harvested from all three pots that represented one replicate were combined before weighing.

2.2.7 Statistical analysis

Data were analysed using Statistical Analysis System (SAS) software (version 9.4, SAS Institute Inc., Cary, NC, USA, 2000) for Analysis of Variance (ANOVA). Seasonal homogeneity of variance was tested with Levene's test, after which the results of both seasons were merged and studied in a single overall ANOVA. The Shapiro-Wilk test was conducted for deviation from normality and insignificant interactions. Fisher's least significant difference was calculated at the 5% level to compare treatment means. For all tests, a probability level of 5% was considered significant. Pearson correlation coefficients (r), correlating Swiss chard's growth and yield parameters, were derived using the CORR procedure of SAS 9.4.

3. Results and Discussion

3.1 Effect Of Zeolite On The Growth Parameters Of Swiss Chard

Leaf chlorophyll content, number of leaves, height, leaf width, and length were used as non-destructive growth measures on leafy vegetables. Figure 1 (A-D) shows the growth parameters of Swiss chard grown on zeolite-amended sandy soils at 59 days after transplanting. Leaf chlorophyll content index (CCI) had higher values in the second season (2019) compared to the first season (2018). Additionally, the non-amended treatment (0%) showed better leaf CCI values compared to the zeolite-amended treatment, except for 20% zeolite application in the first season and 30% zeolite application in the second season. The leaf CCI is related to the nitrogen (N) and the water status of the plant, a decrease in leaf CCI at the end of a crop life is normally associated with leaf senescence (Khaleghi et al., 2012; Sánchez-Sastre et al., 2020). Zeolite, due to its porous nature and affinity towards ammonium (NH_4^+) cations may regulate plant water and N uptake (Gül et al. 2005; Ramesh and Reddy, 2011). Zeolite has been observed to increase soil water holding capacity (Shahbaz et al., 2019; Mahmoud and Swaefy, 2020).

The study found an increased wheat photosynthetic rate, with zeolite application (100 g kg^{-1}; 50 g kg^{-1} application). That analysis found higher photosynthetic rates [μmol/m2/s], on sage plants grown on soils treated with nano-zeolite (30 g L^{-1} zeolite-irrigation water) (Shahbaz et al., 2019; Mohmoud and Swaefy, 2020). In both studies, this was attributed to improved soil moisture holding capacity with zeolite application. The findings of this study contradict these author's findings and may be due to the differences in zeolite application rate. The high application of zeolite in this study may have increased zeolite affinity towards NH_4^+ in the soil solution, allowing for zeolite to adsorb most of the NH_4^+ in the soil into its cavities. Zeolite cavities and their high cation exchange capacity may allow zeolite to adsorb cations with a greater force than that of plant roots for nutrient assimilation (Valdivia et al., 2021). However, the benefit of the adsorption is that it allows for significant amounts of essential nutrients, particularly NH_4^+, to be retained in the soil and prevents them from leaching (Liu et al., 2023).

Swiss chard number of leaves per plant (Figure 1-B) shows that there were no differences ($p \geq 0.05$) in the first growing season (2018). In the second growing season, there was an increase in the number of leaves per plant with the increased application of zeolite. The leaf area (cm^2) results also show that there were no differences ($p \geq 0.05$) among the zeolite-amended treatments, while the non-amended treatment had reduced ($p \leq 0.05$) leaf area in the first growing season. In the second growing season, the leaf area increased with the increase in zeolite application. This can be linked to zeolites' long-term improvement of soil quality, as previously reported by Sindesi et al. (2023a) (2023b) and (2024). Soil pH, soil total K, soil exchangeable cations (Ca, K, Mg and Na) and cation exchange capacity were all improved in the study due to zeolite application. Additionally, improved soil water holding may also be attributed to the increase in the number of leaves and leaf area in the second growing season. In the initial growing season, the zeolite may not fully integrate with the sandy soil, leading to uncertain results and trends in Swiss chard growth. These findings suggest that zeolite may need more time to fully integrate into the soil system and positively impact plant growth. This phenomenon is also noticeable in the results for Swiss chard plant height (Figure 1-D). Plant height slightly ($p \geq 0.05$) decreased on the non-amended treatment from 2018 to 2019, while on the zeolite-amended treatments, all the plant heights improved from the initial growing season to the 2019 season.

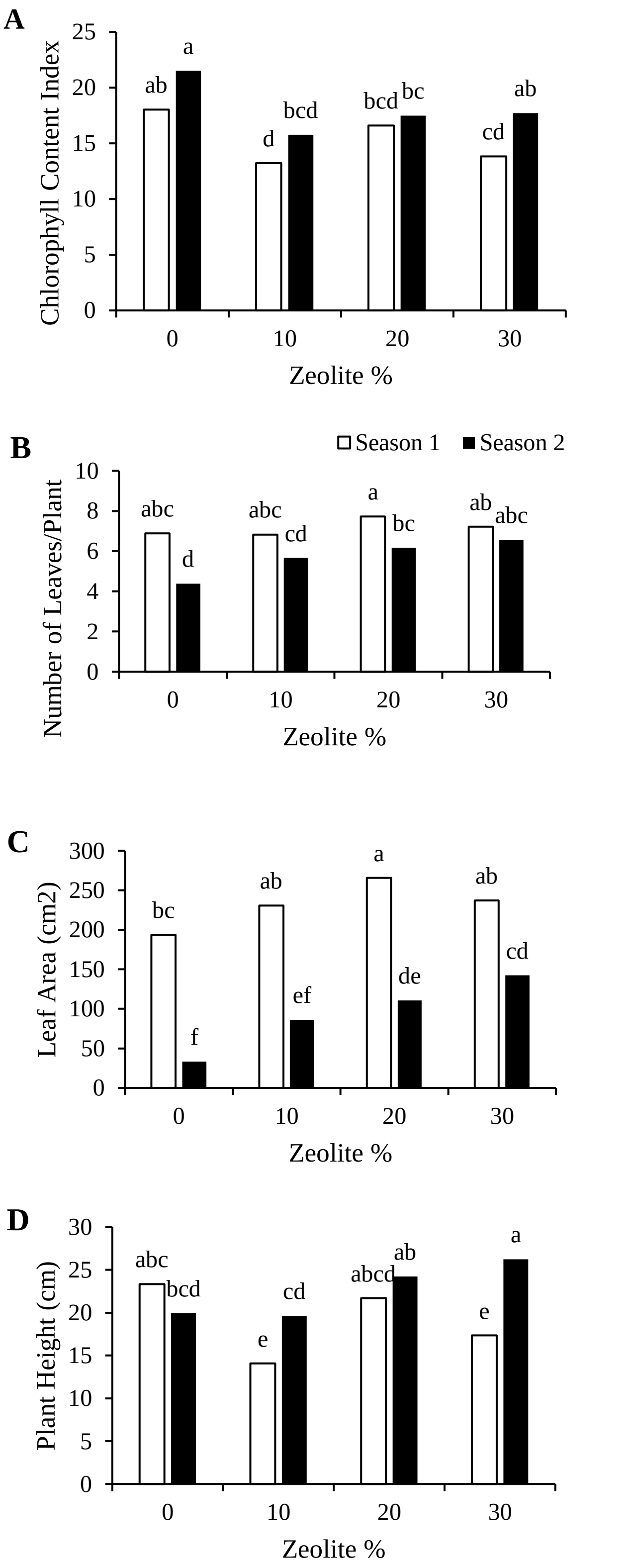
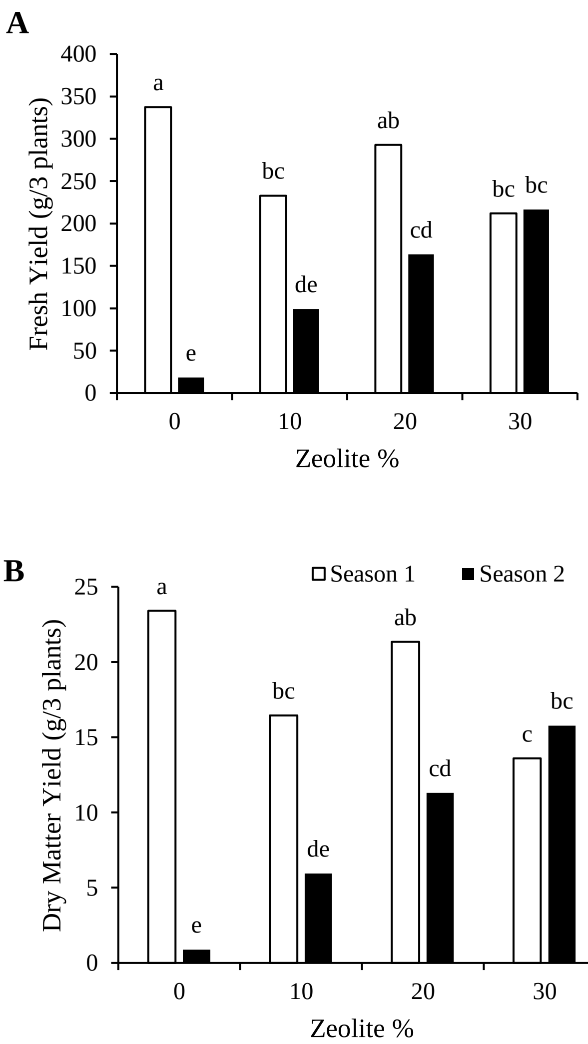


Figure 1: Swiss chard growth responses to zeolite application. Bars with different letters show significance at p ≤0.05. Season 1: 2018-late autumn to late spring, Season 2: 2019-early autumn to early spring, LSD: A=4.01; 1.37; 26.69; 4.57.

3.2 Swiss chard yield parameter responses to zeolite application

Swiss chard yield parameters are represented in Figure 2 (A-C) below. In the initial growing season, both fresh and dry matter yield (g/3 plants) showed better weight on the non-amended treatment and the 20% zeolite amended treatment. Generally, these two yield parameters were slightly better on the non-amended treatments in the first growing season. In the second growing season, the two yield parameters were reduced on the non-amended and zeolite-amended treatments compared to the initial season, except for the 30% zeolite treatment. In the second growing season, a general increase was observed with the increase in zeolite application. In the initial growing season, zeolite may have not yet fully integrated into the soil system, and during the process of integration may have reduced some essential plant-required nutrients, such as NH_4^+ (Omar et al., 2015; Liu et al., 2023; Doni et al., 2024). Zeolite has been noted to adsorb cations such as NH_4^+ and K^+ into its structures and slowly release them into soil for plant use (Louhar, 2020). During the initial integration period, these nutrients may be temporarily unavailable for plant uptake as the zeolite absorbs them. Subsequently, they can be slowly released through a gradual exchange-induced dissolution process (Hartman and Fogler, 2007; Louhar, 2020). Zeolite dissolution can be influenced by factors such as pH, with acidic conditions potentially accelerating the dissolution of the zeolite structure (Hartman and Fogler, 2007). The soil pH of the initial soil used was slightly acidic (5.4_{KCL}).

Swiss chard leaf moisture % did not significantly differ (p≥0.05) in the initial growing season (Figure 2-C). However, the 10 and 30% zeolite treatments showed slightly better moisture content than the other treatments in season 1. In the second growing season, the moisture content tended to reduce with increased zeolite application, with significance (p≤0.05) observed among some treatments. The 0 and 10% treatments showed higher moisture content than the other treatments. Crop moisture in crops assists in maintaining the protoplasmic contents of the cells as it encourages cellular functions and plant growth (Udousoro and Ekanem, 2013). However, in this study, higher growth was observed on the zeolite-amended treatments for the second growing season. As such, the low moisture content in the zeolite-amended treatments may be linked with the fact that Swiss chard cultivated under these treatments had higher leaf growth, which may have encouraged greater transpiration losses. This is further strengthened by the larger irrigation requirement that the Swiss chard needed in the second season as previously observed in (Sindesi et al., 2023).



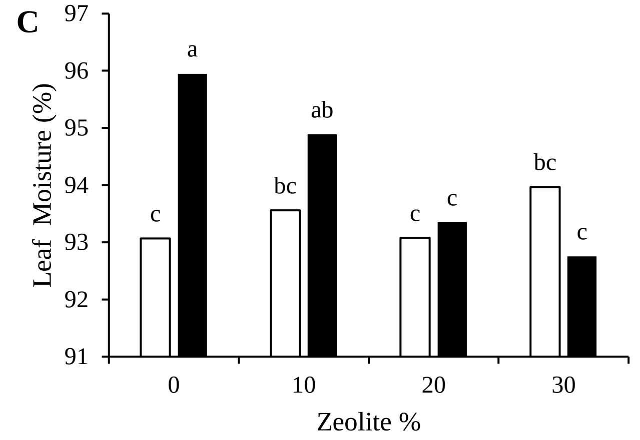
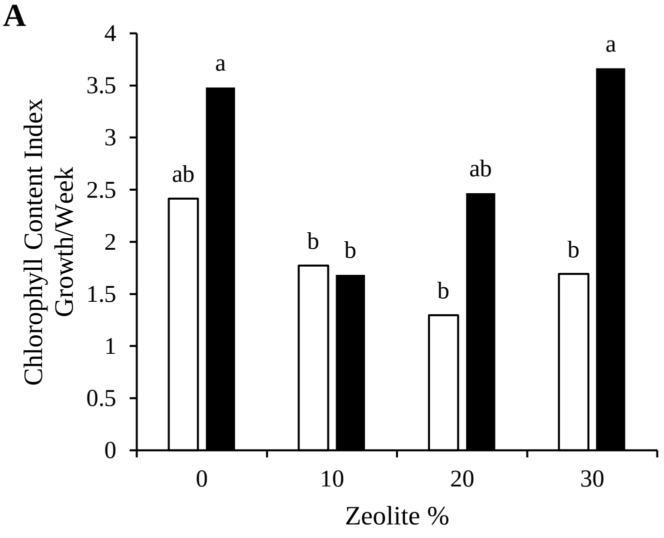


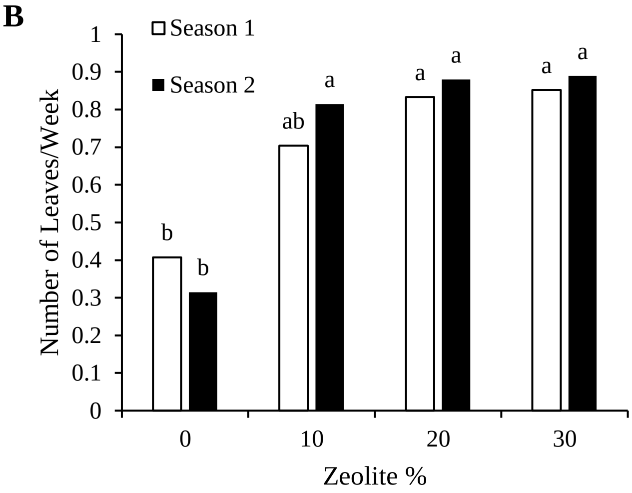
Figure 2: Effect of zeolite application on the yield of Swiss Chard. Bars with different letters show significance at p ≤0.05. Season 1: 2018-late autumn to late spring, Season 2: 2019-early autumn to early spring, LSD: A= 85.49; B= 6.39; C= 1.352.

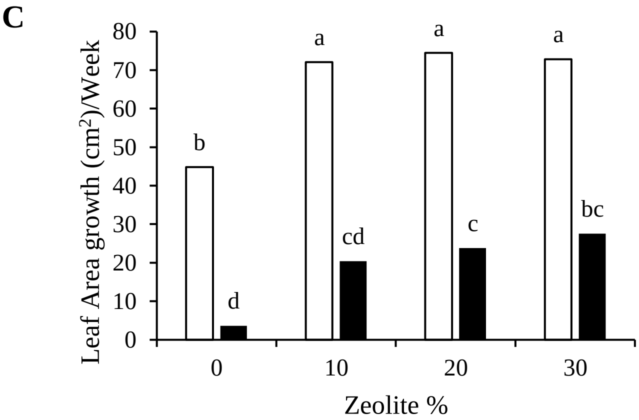
3.3 Effect of zeolite on the growth of Swiss chard

As the availability of growth factors such as water and mineral nutrients increases, the growth rate and crop yield also increase (Motseki, 2008). As such, a faster leaf growth rate in Swiss chard leads to quicker harvests. In this study, the rate of increase of the number of leaves and leaf area increased ($p \leq 0.05$) with increased zeolite application (Figures 3-B and C). This increase can be attributed to improved soil chemical properties (pH, CEC, exchangeable cations and reduced heavy metal availability) and improved water holding capacity (Sindesi et al., 2023a and 2023b). Additionally, the plant height growth rate (Figure 3-D) was not significantly different ($p \geq 0.05$) in the first growing season. However, there was a general increase in the application of zeolite in the second growing season. The growth rate of plant height may have been influenced by resource allocation by the plants (Miao et al.,2024).

The analysis show if plant growth processes draw on the same resource source, such as the phloem tissue carrying products of photosynthesis, then a trade-off might occur between resource allocation to certain aspects of growth (Pyke and Ren, 2023). However, if the growth processes utilise resources from different sources, the trade-offs may not arise. The growth rate of the leaf chlorophyll content index decreased ($p \geq 0.05$) between the non-amended treatment and the 20% zeolite treatment in the initial growing season. It further showed an increasing trend between the 10 and 30% zeolite treatments, with the increase observed in the 30% zeolite treatment being significantly more significant than the growth rate observed in the 10% zeolite treatment. Leaf chlorophyll content index is highly influenced by nutrient availability (N), temperatures and water availability (Hermans and Verbruggen, 2005; Li et al., 2018). Zeolite has been shown to influence soil water holding capacity and nutrient availability (Mahmoud and Swaefy, 2020)







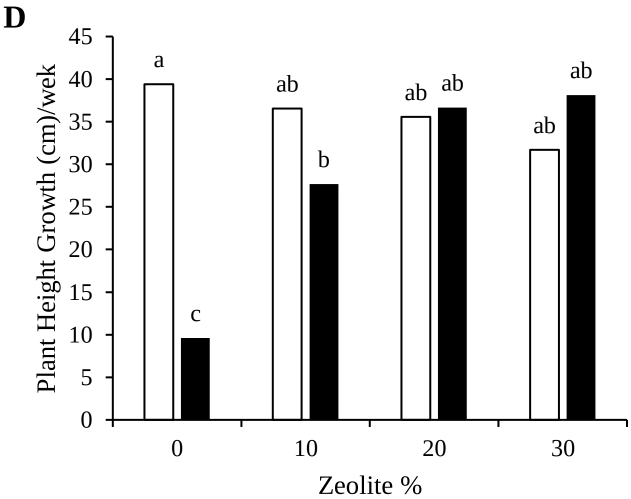


Figure 3: Swiss chard's growth rate responses to zeolite application before harvesting. Bars with different letters show significance at p ≤0.05. Season 1: 2018-late autumn to late spring, Season 2: 2019-early autumn to early spring, LSD: A= 1.66; B=0.41; C=17.44; D=11.06

3.4 Correlation analysis between growth and yield parameters of Swiss chard as affected by zeolite

The correlation coefficient of growth and yield parameters of Swiss chard cultivated under varying rates of zeolite-amended sandy soil are shown in Table 1. Growth parameter at four weeks of data collection (PHW4, NLW4, LAW4) values correlated strongly ($p \leq 0.001$) with the observed Swiss chard yields. Interestingly, at four weeks of data collection, the three growth parameters negatively correlated with Swiss chard leaf moisture content %. Growth parameters at four weeks also had a strong positive correlation ($p \leq 0.001$) with their linked growth rates. As expected, rapid growth rates of these parameters ensure larger plant leaves. However, plant height at four weeks of data collection did not have such a strong correlation with the rate of leaf area growth over the 4 weeks (LAR) of data collection, although it also had a significant positive correlation ($p \leq 0.01$). This may be due to the plants' allocation of resources to certain plant growth parameters, and as observed on the fresh and dry matter yields, it did not affect the plants' productivity. also found strong positive correlations between plant height and yield parameters of cabbage (Head weight and head diameter) grown on organic and inorganic fertilisers (Shakirdeen et al., 2019). This strong and positive correlation shows that plant height is a valuable indicator of potential yield in leafy vegetables; however, it should not be used in isolation.

The chlorophyll content index (CW4) and chlorophyll content index growth rate (CR) did not significantly correlate with any other growth and yield parameters. However, these two parameters showed a strong positive correlation ($p \leq 0.001$). The absence of a significant correlation between CW4 and CR with the yield parameters contradicts the findings observed in the work by (Goggs et al., 2003; Blackmer and Schepers, 1995). The study found a significant correlation between leaf chlorophyll and cotton yield (Goggs et al., 2003). The analysis also found significant positive correlations between chlorophyll content and maise grain yields (Blackmer and Schepers, 1995). The difference in plant species and plant resource allocation may lead to differences in these correlations. These results show that CCI cannot be effectively used to predict Swiss chard growth and final yield.

Swiss chard leaf moisture content % (LM) showed a significant ($p \leq 0.001$) correlation with all the observed parameters apart from the chlorophyll-related parameters. All parameters that significantly correlated with Swiss chard leaf moisture content showed negative correlations. The negative correlation between Swiss chard's moisture content and its growth and yield parameters indicates that the plant prioritises allocating resources towards growth and tissue production rather than water storage. Nevertheless, plants lose water during growth through transpiration. This process occurs when stomata tiny leaf surface pores open to facilitate gas exchange. As the stomata open, water vapour escapes from the leaf's interior into the atmosphere (Hernandez-Candia and Michaelian, 2010). Generally, larger leaves tend to have more stomata, and while this can facilitate greater gas exchange, it also increases the plant's susceptibility to water loss (Kouwenberg et al., 2007). Therefore, the correlation between the growth parameter and the LM can be due to increased stomata and plant growth, leading to increased transpiration.

Table 1: Pearsons' correlation coefficients (r) between Swiss chard growth parameters and yield parameters from zeolite potted sandy soil (Seasons 1 and 2 combined)

Variables	CW4	PHW4	NLW4	LAW4	CR	PHR	NLR	LAR	FY	DMY	LM
CW4	**1**										
PHW4	0.148	**1**									
NLW4	-0.204	**0.503*****	**1**								
LAW4	-0.155	**0.440****	**0.722*****	**1**							
CR	**0.723*****	0.198	-0.134	-0.154	**1**						
PHR	-0.131	**0.866*****	**0.564*****	**0.625*****	0.011	**1**					
NLR	-0.119	**0.408****	**0.764*****	**0.327***	0.028	**0.372****	**1**				
LAR	-0.254	**0.293****	**0.681*****	**0.970*****	-0.213	**0.544*****	**0.307***	**1**			
FY	-0.036	**0.683*****	**0.766*****	**0.880*****	-0.017	**0.739*****	**0.351***	**0.770*****	**1**		
DM	0.027	**0.696*****	**0.738*****	**0.864*****	0.026	**0.716*****	**0.324***	**0.737*****	**0.989*****	**1**	
LM	0.141	**-0.665*****	**-0.610*****	**-0.585*****	0.087	**-0.671*****	**-0.318***	**-0.481*****	**-0.707*****	**-0.739*****	**1**

^{CW4} Chlorophyll Content Index, ^{PHW4} Plant Height, ^{NLW4} Number of Leaves, ^{LAW4} Leaf Area (All those with W4 are actual values on the fourth week of data collection), ^{CR} Chlorophyll Content Index Growth Rate, ^{PHR} Plant Height Growth Rate, ^{NLR} Number of Leaves Growth Rate, ^{LAR} Leaf Area Growth Rate, ^{DMY} Dry Matter Yield, ^{FY} Fresh Yield, ^{LM} Leaf Moisture Content.* Correlation is significant ≤ 0.05 level, **Correlation is significant ≤ 0.01 level, ***Correlation is significant ≤ 0.001 level.

4. Conclusion

This study examined the influence of zeolite on Swiss chard growth and yield at the end of two months over two growing seasons. The study showed that zeolite soil application improved the leaf area and number of leaves at four weeks of data collection in the second growing season. Furthermore, zeolite also improved the fresh and dry yield of Swiss chard in the second growing season. This demonstrates that zeolite may require a fallowing period before fully integrating into the soil system. The study also showed that decreased leaf moisture (%) does not necessarily lead to reduced dry matter yields. It is also clear that plant growth parameters such as plant height, the number of leaves and the leaf area are good indicators of yield potential in leafy vegetables. Future research is still needed to investigate longer zeolite influences on vegetable crops such as Swiss chard.

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