e-ISSN: 2954-4440

ARTICLE

Current Topics in Agronomic Science

https://doi.org/10.5154/r.ctasci.2025.05.08

English version

Zeolite modifies the development of lettuce (*Lactuca sativa* L.) grown in substrate

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Article history:
Received: April 9, 2025.
Accepted: October 16,2025.
Published online:
November 18, 2025

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Abstract

Zeolites are crystalline, nanoporous minerals with a high capacity for water adsorption and nutrient retention, which can be gradually released into the root zone. These properties make them promising materials for improving nutrient availability and crop productivity. The objective of the present study is to evaluate the effect of zeolite incorporation into the substrate on the development of lettuce (*Lactuca sativa* L. cv. Maximus) plants. Seeds were sown in polystyrene foam trays and irrigated with Universal Steiner nutrient solution at 25 and 50 % concentrations. After thirty days of sowing, the seedlings were transplanted into 3 L polyethylene bags containing a mixture of tezontle (particles > 0.5 cm) and zeolite at 0, 2, 4 and 6 % (v/v). The addition of zeolite to the substrate reduced plant height and leaf number at the tested doses; additionally, the 6 % treatment decreased the length of the largest leaf compared with the control. The addition of zeolite to the substrate affects lettuce plant development.

Keywords: Minerals, vegetables, sustainable agriculture, yield.

Introduction

Agriculture, an essential global activity, currently faces two major challenges: increasing productivity to meet growing market demand, and implementing sustainable management practices that enable more efficient use of resources. These challenges arise from the exponential growth of the population and the impacts of phenomena such as climate change, global warming, and ecosystem degradation (Sangeetha & Baskar, 2016).

Consequently, the use of clay-based mineral inputs has gained prominence as a strategy to counteract various factors that limit agricultural production. In this context, zeolite stands out as a material with high potential to enhance the productivity and sustainability of cropping systems (Lahori et al., 2020). Zeolites are crystalline, nanoporous minerals characterized by a high capacity for water and nutrient absorption, which can be gradually released (Zeinalipour & Saadati, 2024), improving nutrient use efficiency in plants and thereby contributing to enhanced yield, soil properties, and overall agricultural productivity (Hassan et al., 2024).

Currently, zeolite is mixed with the soil for its ability to improve their physical and chemical properties, as well as to promote plant growth. Several studies have shown that the addition of this mineral increases the content of exchangeable nitrogen (N), potassium (K), and calcium (Ca), while also preventing their leaching (Ahmed et al., 2010). Furthermore, zeolite application helps reduce the uptake of heavy metals such as lead (Pb), cadmium (Cd), copper (Cu), and zinc (Zn) in cabbage (*Brassica chinensis* L.), maize (*Zea mays*) and rice (*Oryza sativa*) grown in soils contaminated with these elements (Lahori et al., 2020; Rahmany-Samani et al., 2023).

Please cite this article as follows (APA 7): Pacheco, D., Ordaz-Chaparro, V. M. & Ramírez-Olvera, S. M. (2025). Zeolite modifies the development of lettuce (*Lactuca sativa* L.) grown in substrate. *Current Topics in Agronomic Science, 5*. e2508. https://doi.org/10.5154/r.ctasci.2025.05.08

Similarly, zeolite is recognized for its high-water absorption and retention capacity, which increases water availability in the soil and enhances its uptake and use efficiency in plants, thereby allowing higher yields even under drought conditions (Hazrati et al., 2017; Hassan et al., 2024; Zeinalipour & Saadati, 2024). Additionally, studies have highlighted that zeolite promotes a slower release of herbicides (Tanaka et al., 2023), thereby extending their effectiveness in crops.

Regarding the use of zeolite as a fertilizer, it has been shown that its addition to the soil enhances the uptake and use efficiency of nitrogen (N), phosphorus (P), and potassium (K) in various cultivated species, including maize (*Zea. mays* L.), tomato (Solanum lycopersicum L.), beans (*Phaseolus vulgaris* L.), spinach (*Spinacia oleracea* L.), lettuce (*Lactuca sativa* L.), canola (*Brassica napus* L.), rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.) and aloe (*Aloe vera* L.) (Ahmed et al., 2010; Bybordi & Ebrahimian, 2013; Li et al., 2013; Ozbahce et al., 2014; Cabrera-Fajardo et al., 2018; Hazrati et al., 2017; Hazrati et al., 2022; Hassan et al., 2024). This improvement translates into increased growth and yield, which is further enhanced when zeolite is combined with inorganic nitrogen and phosphate fertilizers, as it functions as a reservoir that provides a gradual nutrient release, thereby improving plant nutrient use efficiency (Ahmed et al., 2010).

Lettuce (*Lactuca sativa* L.) is a vegetable of high commercial and nutritional value, rich in vitamin A, vitamin K and beta-carotene (Kim et al., 2016). Soilless production systems represent a sustainable alternative that optimizes water use and addresses current challenges related to water availability (Maestre-Valero et al., 2018).

However, few studies have addressed the effect of zeolite when incorporated into growing substrates, as well as its influence on the growth of leafy vegetables. The purpose of this research was to assess the effect of adding zeolite to the substrate on lettuce plant growth.

Materials and Methods

Plant material

For seeding production, lyophilized lettuce seeds (*Lactuca sativa* L.) were sown in polystyrene trays with a capacity of 100 cavities. The seedlings were watered with water only in the first week, and from the second to the fourth week, Steiner's (1984) universal nutrient solution was applied, with a composition of 12.0, 1.0, 7.0, 7.0, 9.0 and 4.0 meq·L^{-1} of nitrate (NO_3^-), phosphate ($H_2PO_4^-$), sulfate (SO_4^{2-}), potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}), respectively, at concentrations of 25 and 75 %. Transplanting was performed thirty days after sowing, selecting plants with at least three true leaves and consistent height (Sharma et al., 2009).

Substrate, Treatments and Experimental Units

Zeolite was obtained from Minerales Lozano. Transplanting was carried out in 3-L polyethylene bags filled with a mixture of tezontle (particles larger than 0.5 cm) and zeolite at doses of 0, 2, 4 and 6 % (v/v), corresponding to the treatments under evaluation. Each treatment consisted of four replicates, resulting in a total of 24 experimental units.

Measurement of variables

The response variables were recorded fourteen days after transplanting (DAT), including plant height (cm), number of leaves, length and width of the larges leaf (cm), stem diameter (cm), and canopy coverage (%). Plat height was measured from the base of the stem to the tip of the longest leaf using a tape measure. Only fully expanded leaves were included in the leaf count.

The length and width of the largest leaf were determined by first selecting the leaf with these characteristics. A ruler was used to measure the distance from the base to the apex for length and at the widest point for width. Stem diameter was measured with a caliper at the midpoint of the stem. Canopy coverage was estimated using the Canopy app, which calculates the leaf canopy area from overhead photographs taken under controlled lighting and distance conditions (Govindasamy et al., 2022).

Data Analysis

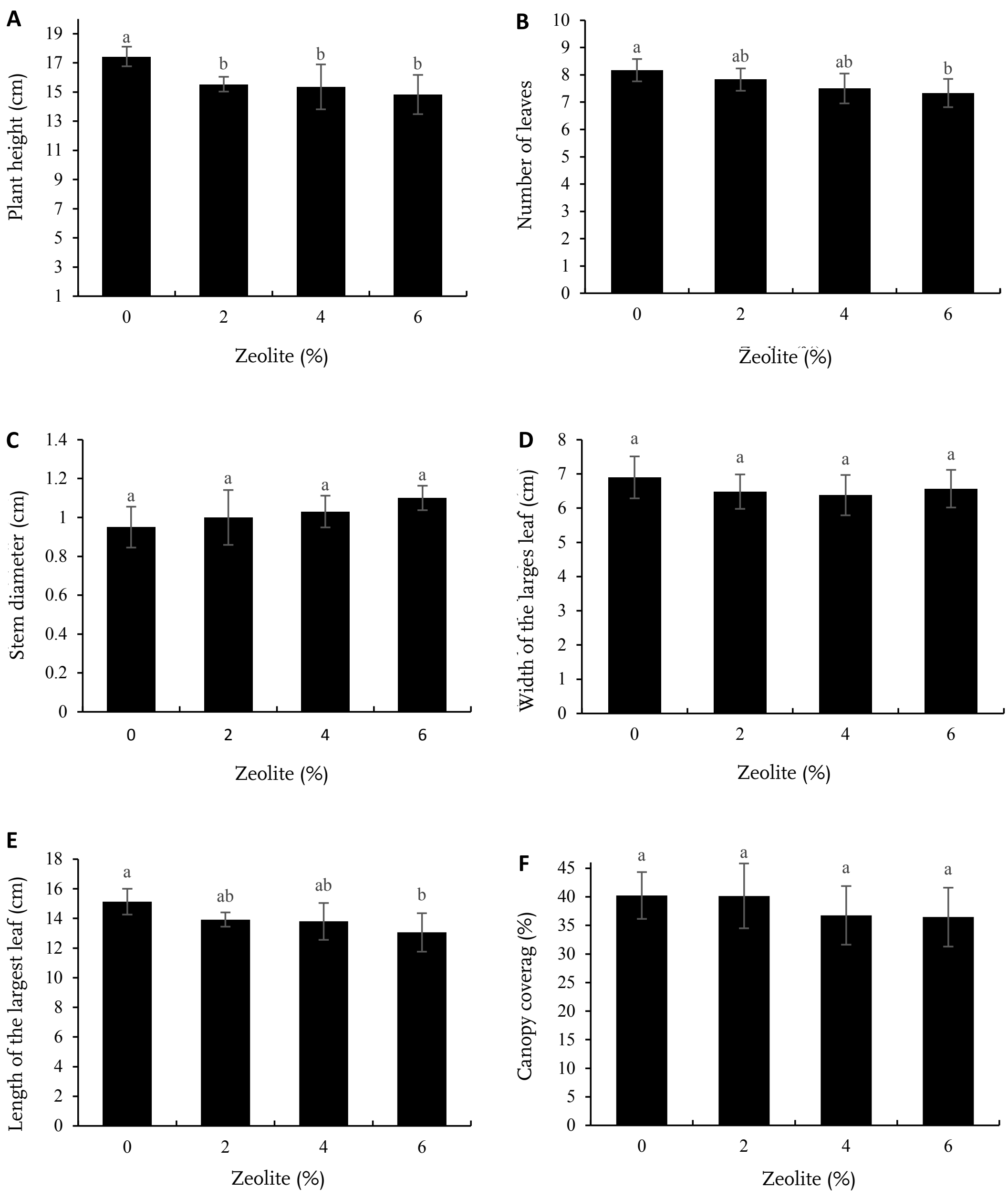
The data for each variable was processed using the R statistical software. The ANOVA was conducted following a completely randomized experimental design, and mean comparisons were performed using Tuke's test ($P \leq 0.05$).

Results and Discussion

Plant height decreased with the evaluated zeolite doses (Figure 1A), while the number of leaves (Figure 1B) and the length of the largest leaf (Figure 1E) were significantly reduced by the 6 % zeolite application compared to the control treatment. In contrast, no significant differences were observed in stem diameter, leaf width, or canopy coverage (Figures 1C, D, F). These results suggest that zeolite may negatively affect variables related to elongation and leaf development during the early growth stages of lettuce.

Although several authors have reported positive effects of zeolite on crop growth and yield such as maize, wheat, aloe vera, coriander (Coriandrum sativum) and strawberry (Fragaria × ananassa) (Ahmed et al., 2010; Hassan et al., 2024; Hazrati et al., 2017; Mahmoud et al., 2023; Zeinalipour & Saadati, 2024), these benefits are generally observed under abiotic stress conditions or when zeolite is applied in combination with synthetic chemical fertilizers. In the present study, conducted under optimal environmental and nutritional conditions, the addition of zeolite had no effect on lettuce growth, possibly due to its high adsorption and cation exchange capacity, which may temporarily

Figure 1. Plant height (A), number of leaves (B), stem diameter (C), width of the larges leaf (D), length of the larges leaf (E) and canopy coverage (F) of lettuce (*Lactuca sativa* L.) plants grown in substrate 0, 2, 4 and 6 % zeolite. Means with different letters indicate statistically significant differences among treatments (Tukey, $P \leq 0.05$)



retain nutrients and decrease their immediate availability to the plant (Szatanik-Kloc et al., 2021).

Moreover, it has been reported that zeolite can retain up to 50 % of its volume in water, but part of this is stored in pores and cannot be taken by roots, limiting effective water availability (Szatanik-Kloc et al., 2021). Similar results were described by Smedt et al. (2017) and Cabrera-Fajardo et al. (2018), who reported either no effects or reductions in the growth of vegetables grown in substrates containing zeolite. These findings suggest that the impact of zeolite depends on the species, environmental conditions, and application method, with more favorable effects observed under stress conditions or during advanced stages of plant development.

Conclusions

The addition of zeolite to the substrate had no effect on the early growth stages of lettuce cv. Maximus. In contrast, its use reduced plant height, leaf number, and leaf length, without significantly affecting stem diameter or leaf width.

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