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Ecological Sustainability of Leaching and N Utilisation in *Solanum Lycopersicum Var. Cerasiforme* Via Green Synthesis of Zeolite LTA

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ABSTRACT

A sustainable green synthesis of zeolite from kaolin was incorporated into loam to reduce leaching and improve environmental sustainability. This research determined the effects of a cation-binding mineral zeolite on nitrogen leaching, nitrogen absorption, and cherry tomato yield in pots. There are seven distinct experimental handlings: Control High (CH); Control Attainment (CS); Control Low (CL); 2g of zeolite(2gZ); 4g of zeolite(4gZ); 6g of zeolite(6gZ); and 6g of commercial zeolite (6gIZ) grown in a greenhouse. A design replicated 30 times. The implementation of the Least Significant Difference (LSD) post-hoc test ($P \leq 0.05$) enables the effectiveness measurement of all loam handlings towards leaching and N utilisation in loam. According to the results, 6g of zeolite shows the smallest, highly significant difference in the mean concentrations of nitrite and nitrate compared with the other handlings ($p < 0.05$). Regarding the average nitrogen concentration in the loam at each harvest, the 6 g zeolite handling distinctly increased the average loam nitrogen concentration compared to other handlings ($p < 0.05$). There was no statistically significant difference in fruit mass between handlings ($p > 0.05$); however, the handling with 6 g of zeolite produced the highest mean fruit mass overall. In conclusion, with the zeolite capacity expressed as Cation exchange capacity (CEC), this green-synthesised zeolite reduced water discharge from a container while increasing the average nitrogen concentration in the loam.

Keywords: *Zeolite LTA; Nitrogen; Leaching; Cherry Tomato*

1. INTRODUCTION

The tomato, scientifically referred to as *Solanum lycopersicum L.*, is classified in the family Solanaceae and is recognised as a highly important and popular vegetable. The cherry tomato is just like a normal tomato, but it is smaller [1]. Cherry tomatoes contain vitamins A, B, C, and D, as well as minerals such as calcium (Ca), phosphorus (P), and iron (Fe) [2]. A single medium-sized tomato, weighing approximately 145 grams, already provides a daily portion of about 40% of Vitamin C and 20% of Vitamin A [3]. The tomato belongs to the Solanaceae family as a plant-vegetable fruit [4]. The tomatoes are originally from South America, but nowadays we can find them everywhere. Overall, there are more than 7,000 tomato varieties[5].

The cherry tomato has the Latin name Solanum Lycopersicum (L.) var. cerasiforme Mill. People usually consume cherry tomatoes. Cherry tomatoes are small and red, like cherries[6]. Cherry tomatoes are grown in summer or in warm regions. However, due to greenhouse cultivation methods, people can currently grow them even when the area is not very warm [7] or in shaded areas [8]. These growing methods are still producing large amounts of fruit and are more affordable because they do not require many resources. During insertion, cherry tomatoes covered with shade are protected from unstable weather conditions that could damage them [9-10]. The growth phases of a tomato plant consist of germination and early growth, marked by the emergence of initial leaves for 25 to 35 days; the next phase is vegetative for 20 to 25 days. Normally, the plant has a flowering stage for 20 to 30 days, then enters early fruiting for 15 to 20 days, and begins producing fruit [11]. The early growth stages are marked by leaf growth, which occurs over 25-35 days. The duration from harvest to seed formation in cherry tomatoes is approximately 45 to 100 days [11].

Nitrogen (N) is an important compound because cherry tomatoes need nitrogen to create their protoplasm [12]. Nitrogen is also needed to increase cherry tomato yields. N, also known as nitrogen, helps the plant's growth because it contains chlorophyll and numerous enzymes. The potential enhancement in crop yield resulting from nitrogen application may be attributed to increased panicle formation in cereals and pod formation in legumes [13]. The application of nitrogen has been found to reduce grain sterility and increase grain or seed mass [13].

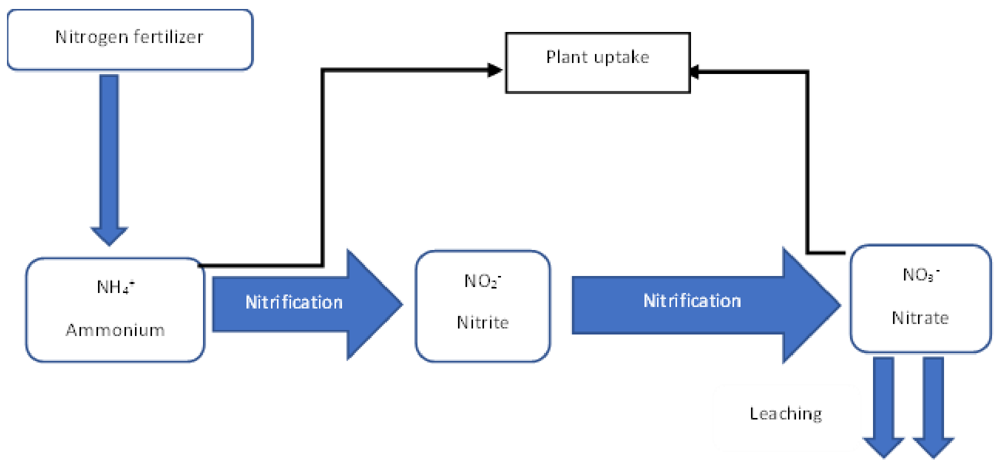

Figure 1. Nitrogen cycle.

Furthermore, the grain-to-straw ratio and harvest index of nitrogen (the uptake of nitrogen in the grain divided by the uptake of nitrogen in both the grain and straw) are positively correlated with yield in field crops and can be enhanced through the implementation of nitrogen [14]. Ammonium (NH_4^+) and nitrate (NO_3) are other forms of nitrogen (N) that are found in loam [15-16]. However, the high nitrogen content of loam leads to leaching that contaminates water sources. So, it is important to measure the amount of fertiliser used and the timing of fertiliser application to the plants. The presence of a high concentration of nitrogen in the loam when there is no crop or when the crop's nitrogen demand is minimal, such as before emergence or at harvest, can lead to significant losses through leaching [17].

Furthermore, the leaching of NO_3^- appears to be more pronounced when there is a confluence of elevated NO_3^- levels within the loam profile and a subsequent period of intense precipitation or substantial irrigation. The fertilisers are applied to the loam, especially when the weather is conducive to heavy rainfall, thereby increasing nitrogen use efficiency (NUE) and reducing NO_3 losses [18]. NO_3 can be reduced by leaching. However, these leachates are dangerous if they enter groundwater. There are four primary categories of nitrogen (N) that can be found within loam: (a) N that is found within organic matter, (b) N that is a component of microbial bodies, (c) NH_4^+ ions that are bound to the surfaces of clay particles and organic matter, and (d) N has several forms, specifically NH_4^+, NO_3^-, and small amounts of NO_2^- in the loam.

The use of nitrogen (N) fertilisers in large amounts on cultivated lands leads to water pollution [19] that can affect the quality of agricultural products [20-21]. To reduce nitrogen leaching, farmers use more irrigation water [22] to improve vegetable quality [23]. Nitrogen can react with other organic compounds and fix the loam conditions [24]. Other forms of nitrogen can leach into groundwater [25-26]. Nitrogen is a compound that makes up Earth's atmosphere, so it is abundant [27]. The formation of nitrate and ammonium ions can be used in irrigation, as shown in Fig. 1. However, they are not entirely safe for irrigation because high concentrations of nitrate and ammonium can cause pollution, especially in aquatic environments, and adversely affect human health [28].

Zeolites consist of hydrated aluminosilicate that is formed by the oxygen, tetrahedral alumina (AlO_4), and silica (SiO_4)[29]. The material in question expresses an open void with a three-dimensional crystal structure characterised by the coordination of aluminium, silicon, and oxygen with active metals. Zeolites consist of aluminium, oxygen, or phosphorus atoms arranged in a tetrahedral structure, which serve as the primary building blocks. Zeolites consist of aluminosilicate frameworks, so they have a tetrahedral structure formed by silicon and aluminium ions [30-32]. Zeolites have many types, including zeolite A, X, Y, and P [33]. Zeolites A, X, and Y have a cubo-octahedral structure [34]. Zeolites X and Y have high stability and a compact crystalline structure [35]. Zeolites are used in commercial, agricultural, and even biomedical implementations [36].

Zeolites can be applied in agricultural processes because they exhibit cation exchange, molecular sieving, and high adsorption capacities [37]. These compounds act as fertilisers because they absorb water to reduce water loss in plants and can also bind other electrolytes important for plant growth [38]. A study reported that zeolites exhibit selective absorption of ammonium ions (NH_4^+) to reduce nitrogen losses and leaching into loams [39]. Zeolites can maintain loam's water content through their aerated porosity [40]. Zeolites have been reported to hold more water, around 5-15% of the loam, than in sandy loam [41]. Because sand loam has low porosity, which reduces its cation exchange capacity [42]. Conversely, zeolite-treated loam displayed a porosity of 0.437, a density of 1.60 Mg m^{-3}, and a cation-exchange capacity (CEC) of 1.6 cmol (+) kg^{-1}, according to the same parameters. These compounds reduced water use through their highly porous structure, which increases water accommodation in the loam [43]. In tomato (*Solanum lycopersicum*), zeolite-enriched loamless media increased CEC, reduced nutrient leaching, and developed fruit yield [44]. In sweet corn, zeolite loam amendment affects the loam's characteristics, including cation exchange capacity, thereby improving growth and yield [45]. Zeolites have been found to facilitate remoistening, promoting the movement of water toward the resulting moisture and thereby conserving the requisite water for agricultural irrigation [46]. Previous research has reported that using zeolites to exchange ammonium (NH_4^+) and phosphate (P) ions is more effective at transporting water and nutrients to plants [47]. Thus, this research reports the use of zeolite to modify and control nitrogen leaching while maintaining its high cation exchange capacity.

2. MATERIALS AND METHODS

2.1. Synthesis of Zeolite from Kaolin

The kaolin mineral is processed by calcination in a furnace at 600°C for 4 hours to become metakaolin. About 3 grams of metakaolin was added to a beaker containing 60 mL of a sodium hydroxide solution. The metakaolin was slowly mixed with a 1 M sodium hydroxide solution. The mixture was continuously mixed for 24 hours at 40°C during the ageing process. After the ageing phase was complete, the solution was transferred into a 100 mL Teflon-lined autoclave and then placed in an oven at 100°C for 9 hours. After 9 hours, the liquid (supernatant) was collected and washed with aquadest until the pH reached 8. At the same time, the solid parts were dried in an oven at 60°C for 12 hours. Then, these dried solid parts were characterised using X-ray diffraction (XRD) and field emission scanning electron microscopy (FESEM).

2.2. Leaching Experiment

This experiment was performed within a controlled greenhouse environment. There are seven handlings in this experiment: Control High (CH); Control Attainment (CS); Control Low (CL); 2g of zeolite(2gZ); 4g of zeolite(4gZ); 6g of zeolite(6gZ); and 6g of commercial zeolite (6gIZ). We used Green World F1 Hybrid as our cherry tomato source. The factors that affect cherry tomatoes' growth are controlled in the same amount for all cherry tomato plants. Those factors are NPK fertiliser quantity, loam type, and watering frequency. The cherry tomatoes' seeds were planted in the tray and left for 28 days. After that, the seeds are moved into individual pots in the greenhouse. For the growth of leaves and fruits, we used EuroCHEM's NPK green and NPK blue. The utilisation of these fertilisers was implemented in a controlled greenhouse experiment. Each experimental group of plants will receive different fertilisation rates. The control high group will be fertilised at a rate of 20g per pot, the control attainment group at a rate of 12g per pot, the zeolite group at a rate of 2g per pot, the 4g zeolite group at a rate of 4g per pot, the 6g zeolite group at a rate of 6g per pot, and the commercial zeolite group at a rate of 6 g per pot. The control low group will receive a fertilisation rate of 5g per pot.

Each handling was run three times. The loam was purchased from Kean Beng Lee Industries and contained coco peat, burnt loam, river sand, burnt husk, rich humus, and charcoal powder. The greenhouse is 5.5 metres long, 2.8 metres wide, and 2.5 metres high. The leachate was collected from four pots in equal amounts. The concentrations of nitrite, nitrate, and ammonium in the leachate were measured weekly by sampling the leachate. In Week 1, the leachate sample was collected 28 days after seed sowing. The leachate samples were also analysed by ion chromatography to determine the concentrations of nitrite and nitrate.

2.3 Nitrogen Analysis in Loam

The nitrogen in loam is measured using the Kjeldahl method by titrating with a strong acid solution, and the titration result is converted to the total organic nitrogen content of the sample.

2.4 Yield Analysis (Fruit mass)

Yield analysis was conducted by weighing the fruits harvested at 8 and 12 weeks after planting cherry tomato seeds using a digital analytical balance.

2.5 LSD Test

Each outcome was analysed using statistical methods to determine the least significant differences (LSD) between the various handlings. The statistical outcomes were assessed using SPSS, version 10 for Windows. The plants and loams were measured at each harvest period using a one-way analysis of variance (ANOVA). SSPS and ANOVA are required to determine the least significant difference (LSD) of cherry tomatoes in every experiment.

3. OUTCOME AND DISCUSSION

3.1. Synthesis of Zeolite Characteristics

The zeolite's average diameter was 497 nm, as characterised using a particle size analyser [48]. The mean diameter of zeolite, as determined at the conclusion of the analysis, is 43.8 nm, which is equivalent to 0.0438 micrometres. The unprocessed kaolin sample displayed a similar X-ray diffraction (XRD) pattern to that of kaolinite, a mineral characterised by [0 0 1] and [0 0 2]reflections at2θΘ values of 12.398° and 24.944°, respectively (Fig. 2) [49]. Based on Figure 2, it has been determined that the single mineral is kaolin because the X-ray diffraction (XRD) pattern of kaolin shows two specific peaks at 2θ values of 12.3° and 24.8°, which match the PDF card 00–058-2001 [50]. At an angular range of 2Θ = 20–24.5° and 2Θ = 35–40°, insertional low-intensity reflections were observed in relation to the edge of the kaolinite crystal [51]. Following the process of calcination, the X-ray diffraction (XRD) pattern of metakaolin undergoes alterations, characterised by shifts in peak intensities within the range of 2θ = 20.861 and 26.644, specifically at a temperature of 600 °C (refer to Fig. 2). The peaks at 600 °C show that quartz is the primary component of the zeolite, the peaks were shown at 2θ angles, which are 10.158, 12.449, 16.093, 20.397, 20.857, 21.649, 23.966, 26.089, 26.637, 27.092, 29.916, 30.804, 32.515, and 34.150 [49], as shown in Figure 2.

Kaolinite has a hexagonal structure, and it was confirmed by SEM as depicted in Fig. 3. The unprocessed kaolin samples display a lamellar structure in their morphologies [52]. The production of amorphous metakaolin as an outcome of the calcination process [49,53]. Figure 3 depicts the SEM imaging results that provide evidence of the congruence between the synthesised Zeolite-LTA and the cubic crystalline system family. Figure 3 depicts zeolite crystals exhibiting a high degree of crystallinity, with a uniform cubical structure and uniform diameter. The cubic arrangement of the zeolite crystals was clearly evident, with an average length of less than 2 μm.

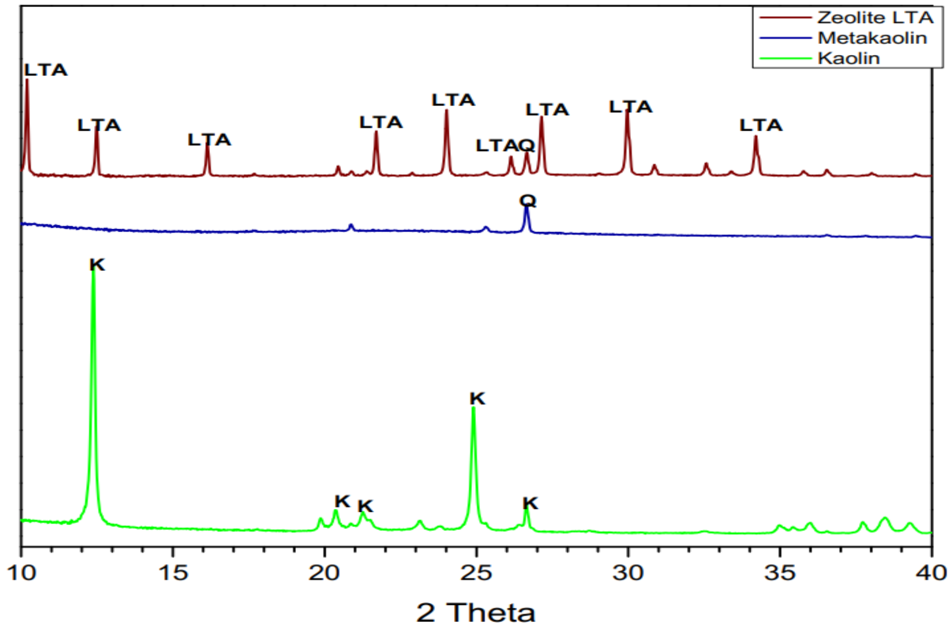

Figure 2. XRD analysisi of (a) kaolin, (b) metakaolin and (c) zeolite LTA;K: kaolinite, Q: Quartz; LTA; Zeolite LTA.

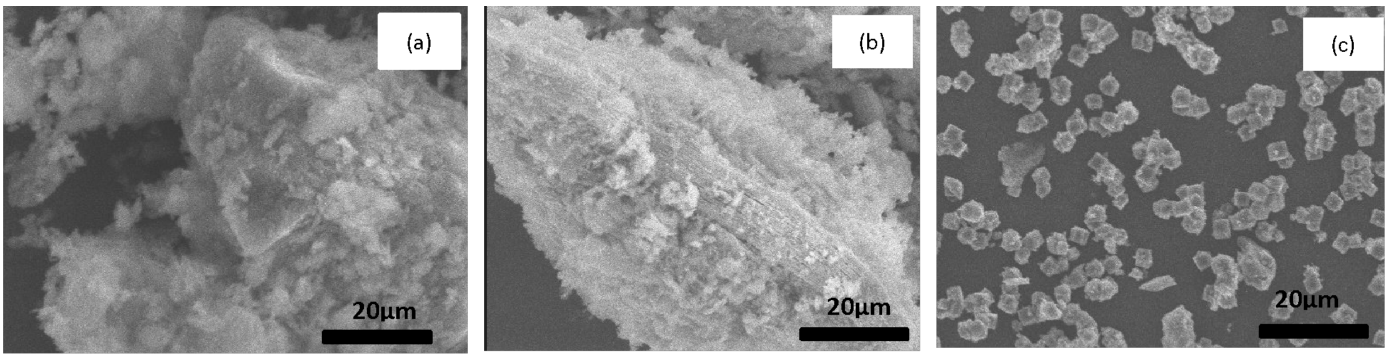

Figure 3. FESEM analysis of (a)kaolin, (b)metakaolin and (c)zeolite.

3.2 Nitrate and Nitrite Analysis

Tables 1 and 2 present the mean values of nitrite and nitrate, respectively, from week 1 to week 12. The statistical analysis reveals that the average nitrate concentration at week 1 shows a very distinct difference among all handlings when 6g of Zeolite is applied, as well as in the control group, with a high nitrate concentration. The control attainments show the distinctive outcome of the experiment. During the second week of the experiment, notable variations were observed among all handling groups regarding the implementation of 2 g, 6 g, and commercial Zeolite. No statistical significance is observed in the control group when considering attainment alone. Similarly, in the control low group, no statistically significant difference is observed when considering only 4g of Zeolite. Distinctive outcomes were observed for all handlings involving nitrite, specifically with the utilisation of 2 g, 4 g, and commercial zeolite. During the third week of the experiment, it was observed that all handlings, including nitrate, control high, control low, 4g, 6g, and commercial Zeolite, expressed a high level of significance. Distinctive outcomes were observed for all handlings, including nitrite, control high, control attainment, control low, and 6g of zeolite. In the fourth week, all handlings expressed a statistically distinctive relationship with each other in terms of nitrate levels. Distinctive outcomes were observed for all handlings involving nitrite, including the control high, control attainment, 2 g, 6 g of Zeolite, and commercial zeolite handlings. During the fifth week, a very distinct difference was observed between all handlings regarding nitrate levels. Distinctive outcomes were observed for all handlings involving nitrite, with 2g of Zeolite, 6g of Zeolite, and commercial zeolite demonstrating significance.

Table 1 Mean concenctration (mg/L) of nitrite from 1st until 12th week

Treatment	Week (Nitrate)											
	1	2	3	4	5	6	7	8	9	10	11	12
CH	0.07e	0.01c	1418.13f	1356.18a	1609.35a	1658.41a	735.91f	298.09a	489.17g	210.5625a	568.6325a	261.2300a
CS	0.08fh	0.01d	1172.32d	895.18b	1024.40b	1263.88b	496.65e	357.37b	197.38f	96.1650b	208.6725b	177.0250b
CL	0.04bc	0.02e	1122.20c	652.19c	594.46c	1141.32c	189.94c	152.59c	117.19b	106.3975c	355.4150c	119.3250c
2gZ	0.05cd	0.01b	977.38b	416.66d	572.40d	487.54d	125.24b	145.68d	84.12c	88.3000d	88.1700d	109.4750d
4gZ	0.08gh	0.02e	1174.45d	312.68e	401.25e	474.99e	105.88a	92.22e	75.78a	66.5250e	74.1350e	84.8100e
6gZ	0.01a	0.01a	929.75a	304.28f	301.23f	404.95f	186.88c	73.35f	74.93a	71.4425f	66.6850f	44.2975f
6glZ	0.05cd	0.16f	1656.17g	1633.59g	1349.46g	516.59g	479.01d	287.33g	84.24c	168.6875g	106.3425g	182.8800g
LSD (p≤0.05)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.0010	0.0010

N.B where means have been given the same common letter, they do not differ at p≤0.05. following an LSD test

Table 2 Mean concenctration (mg/L) of nitrate from 1st until 12th week

Treatment	Week (Nitrate)											
	1	2	3	4	5	6	7	8	9	10	11	12
CH	0.07e	0.01c	1418.13f	1356.18a	1609.35a	1658.41a	735.91f	298.09a	489.17g	210.5625a	568.6325a	261.2300a
CS	0.08fh	0.01d	1172.32d	895.18b	1024.40b	1263.88b	496.65e	357.37b	197.38f	96.1650b	208.6725b	177.0250b
CL	0.04bc	0.02e	1122.20c	652.19c	594.46c	1141.32c	189.94c	152.59c	117.19b	106.3975c	355.4150c	119.3250c
2gZ	0.05cd	0.01b	977.38b	416.66d	572.40d	487.54d	125.24b	145.68d	84.12c	88.3000d	88.1700d	109.4750d
4gZ	0.08gh	0.02e	1174.45d	312.68e	401.25e	474.99e	105.88a	92.22e	75.78a	66.5250e	74.1350e	84.8100e
6gZ	0.01a	0.01a	929.75a	304.28f	301.23f	404.95f	186.88c	73.35f	74.93a	71.4425f	66.6850f	44.2975f
6glZ	0.05cd	0.16f	1656.17g	1633.59g	1349.46g	516.59g	479.01d	287.33g	84.24c	168.6875g	106.3425g	182.8800g
LSD (p≤0.05)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.0010	0.0010

N.B where means have been given the same common letter, they do not differ at p≤0.05. following an LSD test

By the sixth week, nitrate analysis showed that all the handlings had large gaps or significant differences between the experiments. In the seventh week, it showed that the implementation of 6g of Zeolite had a significant effect on nitrate levels, indicating its efficacy in maintaining low nitrate concentrations. The experimental outcomes indicate that nitrite, control high, control attainment, control low, 6g of Zeolite, and commercial zeolite had distinct effects compared to all other treatments. This phenomenon also happened in the 8th week. The zeolite sample weighing 6 grams showed a distinctive outcome, except for the commercial one. In the ninth week, there was a clear difference in nitrate levels among the handling groups, including the control high, control attainment, and control low groups. A noticeable difference is observed among the various handlings of the 6 grams of Zeolite, except for the 4-gram handling. In the tenth week of the study, it was observed that there was a very distinct difference in nitrate levels between all the handlings. Very distinct results were observed among the nitrite handlings, including control high, control attainment, control low, and commercial zeolites. In the eleventh week, a very distinct difference was observed between all handlings concerning nitrate levels. Very distinct differences were observed between all handlings for nitrite levels, including the control high, control low, and 4g of Zeolite handlings.

The observed outcomes indicate a notable distinction between the control high, control low, 2g, 4g, and commercial zeolite samples, each weighing 6g. In the twelfth week, a statistically very distinct difference was observed between all handlings regarding nitrate levels. A very distinct difference is observed in all handlings between the control and the high and 4g of Zeolite in terms of nitrate levels. The experimental outcomes indicate a notable distinction among the control high, control attainment, control low, and 4g of Zeolite samples relative to the observed 6g of Zeolite.

The mean concentrations (mg/L) of nitrate and nitrite from week 1 to week 12, as presented in Tables 1 and 2, have been graphically depicted in Figure 4. The figure allows a comparison of the mean nitrite concentrations (mg/L) for each handling group: (1) control high, (2) control attainment, and (3) control. The experiment involved the use of different amounts of zeolite, specifically 2 g, 4 g, 6 g, and commercial zeolite. The study also included control groups with high, attainment, and low levels of zeolite. The outcomes are presented in Figure 5, which shows the mean nitrate concentration (mg/L) for each handling method over several weeks.

The process of altering natural Zeolite involves initial preparation through grinding and screening, followed by modification using a sodium salt [54]. This modification alters the pore size and surface area of Zeolite, resulting in an enhanced capacity for ammonium ion absorption. The incorporation of zeolite into loam has been found to enhance nutrient utilisation efficiency. These factors facilitate comprehension of the function that Zeolite fulfils in this process. Adding zeolite to loam in chemical fertiliser formulations decreases nitrogen leaching [55]. Also, nitrogen can occur through volatilisation. To avoid nitrogen loss, we add zeolites to keep nutrients in the loam. So, fertiliser use can be reduced, thereby lowering fertiliser purchase costs [59]. Zeolites can retain these minerals because they offer greater cation exchange capacity (CEC) [60-62]. Furthermore, zeolites can be combined with other compounds to enhance ion-binding performance, which influences plant growth and yields more fruit. A distinctive development in the physical properties of loams and a substantial shift in cation exchange capacity (CEC) can be attributed to numerous positive influences [63].

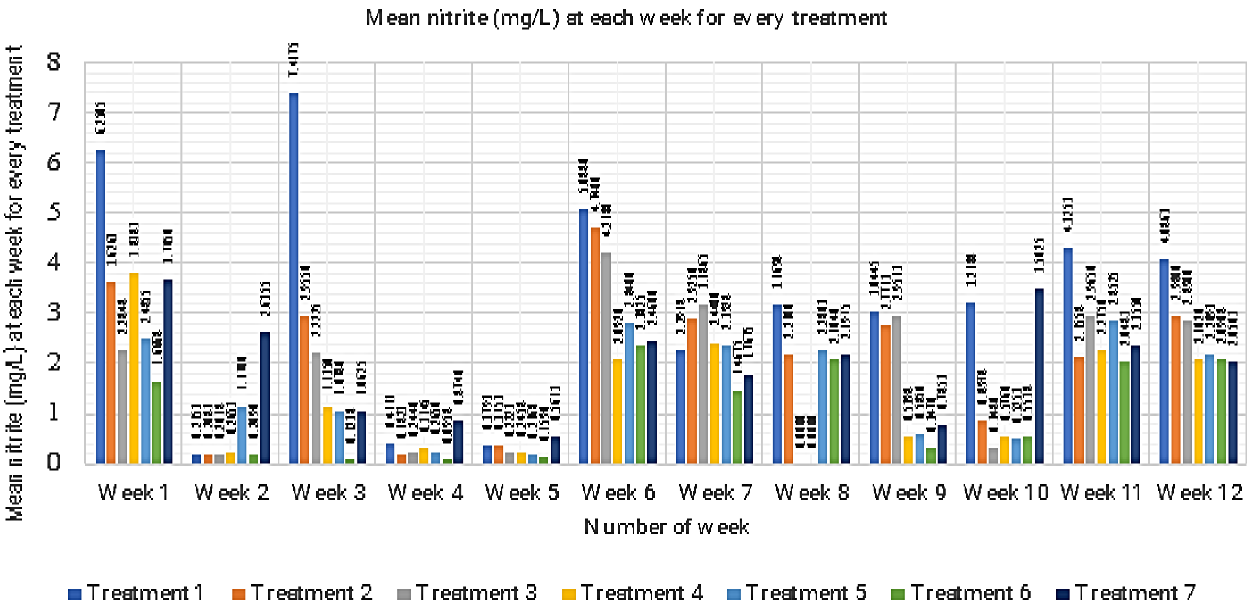

Figure 4. Comparison of Average nitrite(mg/L) at each week for every treatment (1) control High (2) control Standard (3) control Low (4) 2g of zeolite (5) 4g of zeolite.

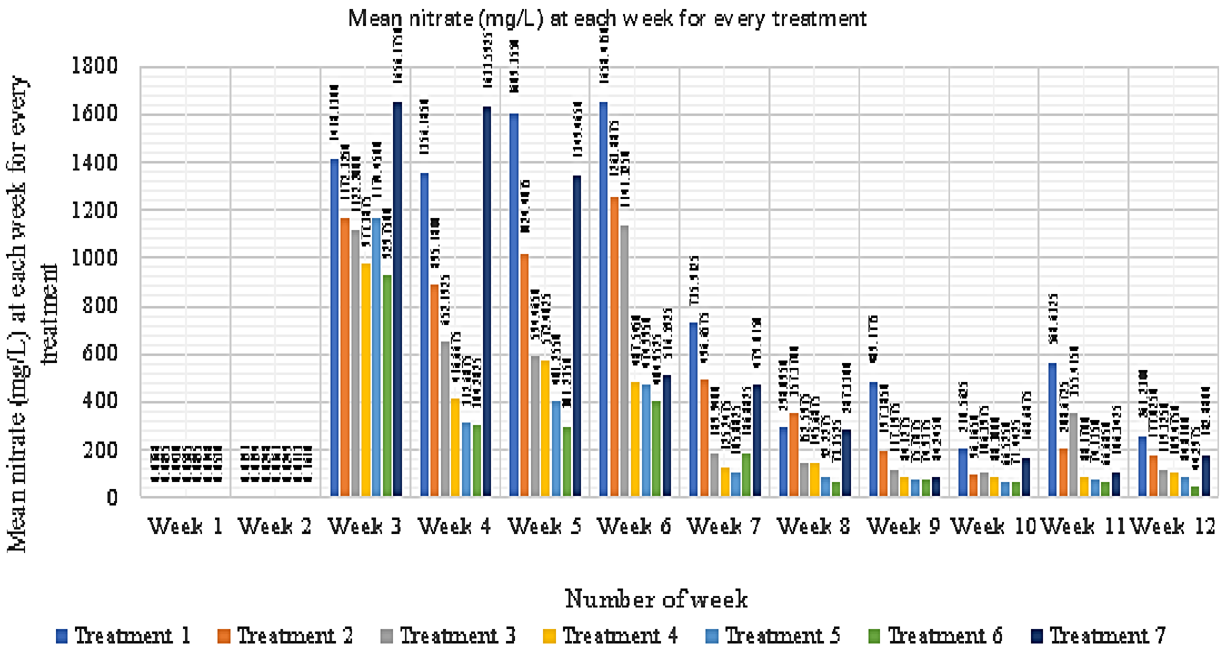

Figure 5. Comparison of Mean nitrate(mg/L) at each week for every treatment (1) control High (2) control Standard (3) control Low (4) 2g of zeolite (5) 4g of zeolite.

Consequently, the implementation of zeolite revisions has the potential to significantly influence the reduction of NH_4^+ leaching [64]. The insertion of 0.2% of clinoptilolite Zeolite by mass into a loamy loam has been found to effectively inhibit the leaching of NH_4^+ when exposed to incoming water. The efficacy of NH_4^+ absorption can be attributed to the clinoptilolite Zeolite. The introduction of clinoptilolite Zeolite, even in small quantities, to loams with sandy and loamy compositions led to a marked reduction in NH4+ levels. The high cation exchange capacity (CEC) and selective uptake of various zeolites, including natural clinoptilolite and artificial zeolites, towards plant nutrients, particularly NH_4^+, can be effectively utilised in the formulation of fertilisers to enhance the loam's ability to hold essential nutrients. This can be achieved by augmenting the capacity for NH_4^+ retention. This objective can be achieved by promoting a systematic, gradual release of these elements, synchronised with the plant's nutrient uptake [65]. Due to its negative charge, the NO_3^- ion typically expresses limited attraction towards loam particle surfaces and does not readily undergo adsorption in loam. However, there have been documented instances of NO_3^- sorption occurring on specific acidic loam types. The application of a fertiliser containing anions, such as KNO_3, to loam has been found to increase nitrogen loss and decrease nitrogen use efficiency (NUE). This can be attributed to the repulsion between the NO_3^- anions and the loam surface [66]. The incorporation of clinoptilolite zeolite into sandy loams has been observed to decrease leachate nitrogen concentration and increase loam moisture and nutrient content. The observed outcome can be attributed to the loam's increased surface area and enhanced cation-exchange capacity [67].

An insertionally salient characteristic of zeolites, which renders them suitable for use in separation and purification, is their inherent ability to provide substantial internal volume [68]. The incorporation of Zeolite into loam has the potential to initially immobilise NH4+ within the loam, thereby restricting the availability of nitrogen to the crop and adversely affecting its growth [58]. Furthermore, the presence of these minerals not only leads to the accumulation of substantial quantities of ammonium ions but also disrupts the nitrification process compared with Zeolite and straight urea (46% N) [69]. Zeolites exhibit a strong affinity for ammonium (NH_4^{+}) ions, enabling them to effectively adsorb this cation from sources such as farmyard manure, composts, and ammonium-containing fertilisers. Zeolites reduce nitrogen loss, which positively influences agriculture by increasing fruit yields due to their phosphorus-absorbing performance [70].

3.2. Residual N in Loam at Harvest 1, 2, and 3

According to the data presented in Table 3. During harvests 1 and 3, the implementation of 6g of zeolite is very distinct compared to the others. During harvest 2, there was a very distinctive outcome. The average nitrogen concentration at harvests 1 and 2 showed that the handling using 6g of zeolite had a higher value than the other handlings. The zeolite consists of cations interconnected by weak bonds, which can be modified by its aluminosilicate structure [71-72]. Zeolite has the inherent ability to bind nutrients, thereby reducing nutrient loss through leaching and facilitating their gradual uptake by plants [73]. This implies potential to enhance land productivity [72]. Zeolite expresses a notable electrostatic property characterised by a consistent negative charge on its surface. This unique feature enables zeolite to possess a substantial capacity for adsorbing cations, including but not limited to potassium, ammonia, calcium, sodium, and magnesium ions, as well as numerous other cations [74]. In the context of zeolites, the interconnected three-dimensional pore structures facilitate the transport of molecules [46]. In the soil, they allow nutrient entry and play roles in the transport, stabilisation, and regulation of mineral fertilisers [75]. The influence of zeolite on nitrogen absorption and plant growth depends on the loam type. The best performance is observed in coarse-textured loams [76].

Zeolites exhibit structural similarities to honeycombs or other cage-like structures, characterised by their substantial void spaces. The presence of aluminium generates a negative charge, necessitating the counterbalancing of cations with a positive charge. Zeolite can hold and store essential nutrients within the root zone, enabling plants to access these nutrients as and when required. Consequently, this leads to enhanced utilisation of nitrogen (N) and potassium (K) fertilisers, which can be achieved by reducing their application rates while maintaining equivalent crop yields, prolonging their effectiveness, or achieving higher crop yields. As a consequence of this phenomenon, the use of zeolites is anticipated to enhance plant growth and development by reducing nutrient loss. The zeolite mineral deposits in their natural state are characterised by the presence of exchangeable cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), and sodium (Na^+). Zeolite can replace various cations with NH_4^+ and other metal cations, depending on the solution pH and the concentrations of these cations [77]. The partial replacement of Si_4^+ by Al_3^- results in the generation of an excess of negative charge. The surplus of negative charge is counterbalanced by alkali and earth-alkaline cations [78].

Furthermore, in addition to water molecules, these cations are distributed throughout the pores and channels within the aluminosilicate macroanion framework [79]. The potential exists to eliminate the water molecule in an alternative manner or replace it with alternative sorbates. Modified zeolites can be obtained for specific applications, such as removing NH_4^+ and hazardous metal cations from wastewater, by substituting metal cations in the crystalline structure [80]. This process can be achieved by replacing metallic cations with alternative cations [78]. Zeolites possess the capacity to adsorb a wide range of polar and non-polar inorganic or organic molecules within the spaces or channels of their structural framework [78].

Table 3 Mean concentration (mg/L) of nitrogen in the loam at harvests 1,2, and 3

Treatment	Harvest 1	Harvest 2	Harvest 3
CH	1.0935a	0.5508b	0.3669a
CS	1.0780a	0.3922c	0.2950b
CL	0.8992c	0.2742d	0.0549c
2gZ	1.1912d	1.2666e	0.4258d
4gZ	1.6785b	1.3689a	0.5517e
6gZ	1.9952e	1.3825a	0.8382f
6gIZ	1.6920b	1.3617a	1.0830g
LSD ($p \leq 0.05$)	0.0001	0.0001	0.0001

N.B. where means have been given the same common letter, they do not differ at p≤0.05, following an LSD test

3.3. Yield of Cherry Tomato

No statistically significant differences were observed among the various handlings (Table 4). However, the fruit mass of the handling amended with 6g zeolite expressed the highest mass in comparison to the other handlings incorporated into the loam. During the second harvest, inserting 6g of Zeolite resulted in a 21.38% increase in the mass of cherry tomatoes compared to the low control group. Compared with other handling methods, the percentage difference in cherry tomato mass ranged from 7% to 16%. During the third harvest, it was observed that the mass of cherry tomatoes increased by 18.31% and 18.51% when treated with 6g of Zeolite, compared with the control group treated with a low amount of Zeolite (3g) and a higher amount of Zeolite (4g), respectively. The application of Zeolite to loam, in conjunction with artificial or organic fertilisers, has been observed to increase yields across various crops. This development in crop productivity can be attributed to the positive effects on loam structure and nutrient conditions resulting from Zeolite implementation [81].

Table 4 Cherry tomato yield(g) at harvest 2 and 3

Treatment	Harvest 2	Harvest 3
CH	94.0a	322.52a
CS	91.10a	352.78a
CL	82.20a	302.72a
2gZ	96.95a	358.58a
4gZ	91.17a	301.98a
6gZ	104.55a	370.58a
6gIZ	87.20a	359.10a
LSD ($p \leq 0.05$)		

N.B where means have been given the same common letter, they do not differ at p≤0.05, following an LSD test

4. CONCLUSIONS

To conclude, this research showed that 6 g of zeolite exhibited the least variation in the mean concentrations of nitrite and nitrate ($p < 0.05$), indicating a more balanced nitrogen transformation process. Furthermore, this handling had increased the average loam nitrogen concentration at each harvest compared to all other handlings ($p < 0.05$). While differences in fruit mass between handlings were not statistically distinctive ($p > 0.05$), the 6 g zeolite handling consistently produced the highest mean fruit mass across the study period. Controlling the application of nitrogen fertiliser is important to prevent nitrate contamination of groundwater. The outcomes of this study suggest that using 6g of zeolite in loam could reduce nitrate leaching and increase nitrogen absorption, which is good for the growth of cherry tomatoes. The reduction of nitrogen also develops environmental sustainability. The different amounts of zeolite used in these experiments led to distinct differences in the leaching of nitrate and nitrite in groundwater. The high cation exchange capacity of zeolite increases the number of binding sites for N ions. The fruit mass did not show a very distinct difference between all handlings, but 6g of zeolite showed the highest mean fruit mass for harvests 2 and 3 compared to other handlings.

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