Eurasian Journal of Soil Science 2024, 13(4), 312 - 319

Eurasian Journal of Soil Science

Journal homepage : http://ejss.fesss.org

The role of zeolite and mineral fertilizers in enhancing Table Beet (*Beta vulgaris* L.) productivity in dark chestnut soils of Southeast Kazakhstan

Tursunay Vassilina [a], Beybit Nasiyev [b], Aigerim Shibikeyeva [a,*], Nurzikhan Seitkali [a], Samalbek Kossanov [c]

[a] Kazakh National Agrarian Research University, Almaty, Kazakhstan
[b] Zhangir Khan Agrarian Technical University, Uralsk, Kazakhstan
[c] Korkyt Ata Kyzylorda State University, Kyzylorda, Kazakhstan

Article Info
Received : 18.11.2023
Accepted : 01.07.2024
Available online: 05.07.2024

Author(s)
T.Vassilina
B.Nasiyev
A.Shibikeyeva *
N.Seitkali
S.Kossanov

* Corresponding author

Abstract

This study evaluated the effectiveness of zeolite, both alone and in combination with mineral fertilizers, in improving the yield and quality of table beets (Beta vulgaris L.) grown in dark chestnut soils of southeast Kazakhstan. The research was conducted at the Kazakh Research Institute of Horticulture during the 2022-2023 growing seasons using a randomized complete block design with six treatments: control (no fertilizers), zeolite 2 t/ha, N45P45K45 (single dose of mineral fertilizers), N90P90K90 (double dose of mineral fertilizers), zeolite 2 t/ha + N45P45K45, and zeolite 2 t/ha + N90P90K90, replicated three times. The application of zeolite significantly improved soil physical properties, such as water permeability and soil density, enhancing root development and water retention. Nutrient availability, particularly nitrate nitrogen and mobile phosphorus, increased significantly in zeolite-treated plots. The combination of zeolite and mineral fertilizers resulted in the highest improvements, with nitrate nitrogen content reaching 40.5 mg/kg and mobile phosphorus 89.2 mg/kg. Moreover, zeolite reduced heavy metal concentrations, particularly cadmium, by 50% compared to the control. Table beet yield significantly increased with zeolite application, with the highest yield of 62.7 t/ha achieved with 2 t/ha zeolite combined with double dose N90P90K90 fertilizers, compared to 42.8 t/ha in the control. Marketable yield also improved, indicating better crop quality. Nutrient composition of the beets improved, with increased dry matter content (21.9%) and reduced nitrate content (240 mg/kg) in zeolite-treated variants. In conclusion, zeolite, especially when combined with mineral fertilizers, effectively enhances soil health, nutrient availability, and table beet yield and quality.

Keywords: Zeolite, Table beet, dark chestnut soil, nutrient availability, sustainable agriculture.

Introduction

The agricultural sector is fundamental to the economy and food security of Kazakhstan, with vegetable crops playing a significant role (Suieubayeva et al., 2022). However, the excessive use of mineral fertilizers has led to soil degradation, nutrient imbalance, and environmental pollution (Krasilnikov et al., 2022). Mineral fertilizers can leach essential nutrients such as calcium, magnesium, and zinc from the soil, causing soil compaction and acidification. These issues negatively impact photosynthesis and plant resistance to diseases, ultimately reducing crop yields and quality. Furthermore, chemicals in fertilizers can enter the human food chain, posing health risks (Sathiyavani et al., 2017; Barłóg et al., 2022; Khan et al., 2022).

: https://doi.org/10.18393/ejss.1511141
: https://ejss.fesss.org/10.18393/ejss.1511141
Publisher : Federation of Eurasian Soil Science Societies
e-ISSN : 2147-4249

The soils of southeast Kazakhstan, particularly dark chestnut soils, are crucial for agriculture due to their fertility (Maxotova et al., 2021; Zhaksybayeva et al., 2022). However, the productivity of these soils is threatened by unsustainable agricultural practices and climatic challenges. The region experiences a sharply continental climate with significant temperature fluctuations and irregular precipitation, which further exacerbates soil degradation issues(Saparov, 2014). Therefore, sustainable soil management practices are essential to maintain soil health and enhance crop productivity (Lal and Steward, 2013).

Organic fertilizers are often considered the best option for improving soil fertility and plant nutrition due to their balanced nutrient content. However, they can be expensive and not always available in sufficient quantities (Herencia et al., 2007; Baghdadi et al., 2018; Gamage et al., 2023). This has led to an increased interest in alternative soil amendments that can enhance soil properties and crop yields while being cost-effective and environmentally friendly (Sankar Ganesh et al., 2017; Snapp et al., 2023).

Zeolites, particularly clinoptilolite, have emerged as promising soil amendments (Garbowski et al., 2023). Zeolites are natural aluminosilicate minerals with high cation exchange capacities, allowing them to retain and gradually release essential nutrients such as potassium and ammonium (Cataldo et a., 2021; Li et al., 2013). This property makes them effective in improving soil fertility and plant growth. Additionally, zeolites can retain soil moisture, reducing the impact of drought and enhancing water use efficiency (Ippolito et al., 2011; Hazrati et al., 2017). Several studies (Mumpton, 1999; Ozbahce et al., 2015; Shivakumara et al., 2021) have shown that zeolites can significantly improve soil physical properties, nutrient availability, and crop yields. Ippolito et al. (2011) investigated the effects of combining clinoptilolite and urea on silt loam soil in maize (Zea mays L.) cultivation. They found that adding zeolite with urea enhanced the sorption of N-NH_4 and reduced its leaching. Clinoptilolite also increased the moisture content of sandy soil, resulting in higher maize yields with a zeolite application rate of 22 Mg ha^{-1} after six weeks. However, increasing the zeolite rate to 90 Mg ha^{-1} negatively impacted maize yield, likely due to the leaching of excessive Na^+ ions from clinoptilolite, which raised soil salinity.

Kazakhstan has significant deposits of high-quality clinoptilolite, particularly in the Shankanay deposit. Despite its potential benefits, the use of natural clinoptilolite in agriculture has been limited (Sadenova et al., 2016; Vassilina et al., 2023). Recent research suggests that zeolite-enriched fertilizers can enhance the positive effects of natural zeolite, providing a controlled release of nutrients and improving soil health (Jarosz et al., 2022). This study aims to evaluate the effectiveness of zeolite, both alone and in combination with mineral fertilizers, in improving the yield and quality of table beets (Beta vulgaris L.) grown in dark chestnut soils of southeast Kazakhstan. The study focuses on assessing the impact of these treatments on soil physical and chemical properties, nutrient availability, and crop performance.

Material and Methods

Study Area

The research was conducted at the Kazakh Research Institute of Horticulture during the 2022-2023 growing seasons in the Almaty region of southeast Kazakhstan. The experimental site is characterized by dark chestnut soil, a crucial soil type in Kazakhstan that supports a significant portion of the country's agriculture. Dark chestnut soils are known for their fertility and ability to support a variety of crops. The mechanical composition of these soils includes a small amount of sand particles, with silt making up about 18.676% of the soil. The soil's pH is 8.36, with 2.27% humus content, 0.098% total nitrogen, 0.225% phosphorus, and 2.4% potassium.

The climate in the Almaty region is sharply continental, with significant temperature variations between summer and winter. Summers are warm, dry, and mostly clear, while winters are freezing, snowy, and partly cloudy. The average temperature in January is -7°C, and in July it is +28°C, with annual precipitation ranging from 350-600 mm. The growing season receives about 120-300 mm of this precipitation. The Köppen climate classification system classifies the area as warm continental, with mild winters and long, hot summers.

Experimental Design

The experiment was designed as a randomized complete block design with three replications. The experimental plots measured 63 m^2 each. The study included six treatments:

- Control (no fertilizers)
- Zeolite 2 t/ha
- $N_{45}P_{45}K_{45}$ (single dose of mineral fertilizers)
- $N_{90}P_{90}K_{90}$ (double dose of mineral fertilizers)

- Zeolite 2 t/ha + N45P45K45
- Zeolite 2 t/ha + N90P90K90

Soil and Fertilizer Application

Natural clinoptilolite zeolite from the Shankanay deposit was used. The chemical composition of the zeolite included 68.6% SiO_2, 18.5% Al_2O_3, 8.6% CaO, 2.2% MgO, and 1.5% Na_2O. Mineral fertilizers used were ammonium nitrate (34% N), ammophos (12% N, 52% P_2O_5), and potassium sulfate (50% K_2O). Zeolite and mineral fertilizers were applied manually in the fall of 2022 for plowing according to the experimental design.

Crop and Soil Management

The table beet variety 'Kyzylkonyr' was used as the test crop. Standard agronomic practices for the southeast Kazakhstan region were followed. Crops were planted in early spring and harvested manually at maturity. Zeolite was crushed to a particle size of less than 100 nm using a planetary ball mill. Soil and plant samples were analyzed using standardized methods to assess the effects of zeolite and mineral fertilizers on soil properties and table beet yield and quality.

Soil Analysis

Nitrate nitrogen (NO_3-N) content in the soil was measured using an ion-selective electrode method. Mobile phosphorus (P_2O_5) was determined using the Machigin method, which involves extraction with a sodium bicarbonate solution and subsequent colorimetric analysis. Water permeability was measured by applying a constant head of water to the soil surface and recording the infiltration rate over the first and second hours of the experiment. Soil density was determined by calculating the bulk density, which involves dividing the dry mass of soil by its volume (Page et al., 1982; Klute, 1986).

Plant Analysis

Dry matter content of the table beet samples was determined using the gravimetric method, which involves drying the samples at 105°C until a constant weight is achieved. Total sugar content was measured using the Bertrand method, a classical titration method for quantifying reducing sugars. Nitrate content in the table beet samples was determined potentiometrically using a nitrate ion-selective electrode (Kalra, 1997; Jones, 2001).

Statistical Analysis

Descriptive statistics, including means and standard deviations, were calculated for all measured parameters to provide an overview of the central tendency and variability of the data. Correlation and regression analyses were conducted to determine the relationships between soil nutrient levels, soil physical properties, and table beet yield. Pearson correlation coefficients were calculated to assess the strength and direction of the relationships between variables. Linear regression models were developed to predict table beet yield based on significant soil properties and nutrient levels. These analyses were performed using Microsoft Excel.

Results and Discussion

Soil Physical Properties

The application of zeolite significantly improved the physical properties of dark chestnut soil. As shown in Table 1, water permeability increased substantially in both the first and second hours of the experiment in the treated variants compared to the control. This indicates that zeolite treatments enhanced soil porosity and water infiltration, which are crucial for root development and plant growth. Moreover, the bulk density became more uniform, ranging from 1.18-1.20 g/cm^3 in zeolite-treated plots compared to the control.

Table 1. Effect of zeolite and mineral fertilizers on water permeability and bulk density

Treatment	Water Permeability (1st hour, mm/hr)	Water Permeability (2nd hour, mm/hr)	Builk Density (g/cm^3)
Control (without fertilizers)	49.0	23.0	1.18
Zeolite 2 t/ha	86.5	62.8	1.20
N45P45K45	62.3	43.3	1.19
N90P90K90	60.9	40.9	1.19
Zeolite 2 t/ha + N45P45K45	87.2	68.5	1.20
Zeolite 2 t/ha + N90P90K90	89.2	65.1	1.20

The findings of this study align with previous research that underscores the benefits of using zeolite as a soil amendment. The improved soil physical properties, such as increased water permeability and more uniform soil density, support better root growth and nutrient uptake, leading to enhanced crop performance. These improvements in soil structure facilitate greater water retention and aeration, which are essential for healthy root development and efficient nutrient absorption. The results of this study are consistent with those of Al-Busaidi et al. (2008) and Ozbahce et al. (2015), who demonstrated that zeolite application significantly enhances soil physical properties, thereby improving overall soil quality and crop productivity. Karami et al. (2020) showed that the combination of nitrogen fertilization in the form of urea and zeolite significantly increased the water use efficiency in Amaranthus cultivation.

This enhanced water permeability and uniform soil density indicate that zeolite effectively modifies the soil structure, making it more conducive to plant growth. The increased porosity allows for better root penetration and water movement within the soil profile, which is critical for maintaining adequate soil moisture levels and preventing waterlogging. Additionally, the improved bulk density suggests that zeolite helps to create a more stable soil structure, reducing compaction and promoting healthier root systems. By improving these physical properties, zeolite not only enhances the immediate growing conditions for crops but also contributes to long-term soil quality and sustainability. These benefits make zeolite a valuable tool for sustainable agriculture, particularly in regions with poor soil structure or limited water availability.

Nutrient Availability

The addition of zeolite and mineral fertilizers significantly enhanced the availability of essential nutrients in the soil. Table 2 shows that nitrate nitrogen levels increased substantially in all treated variants compared to the control, especially during the germination period. The highest nitrate nitrogen content was observed in the zeolite 2 t/ha + N90P90K90 treatment, indicating improved nitrogen retention and gradual release. Similarly, mobile phosphorus levels increased significantly, particularly in treatments combining zeolite and mineral fertilizers.

Table 2. Impact of zeolite and mineral fertilizers on nitrate nitrogen and mobile phosphorus levels in soil

Treatment	Nitrate Nitrogen (mg/kg)	Mobile Phosphorus (mg/kg)
Control	10.0	31.3
Zeolite 2 t/ha	20.5	45.6
N45P45K45	25.8	50.7
N90P90K90	30.1	55.8
Zeolite 2 t/ha + N45P45K45	35.2	70.7
Zeolite 2 t/ha + N90P90K90	40.5	89.2

The increased availability of essential nutrients, particularly nitrate nitrogen and mobile phosphorus, is crucial for the growth and development of table beets. Zeolite's ability to retain and gradually release these nutrients ensures a steady supply throughout the growing season, which is critical for maximizing yield. This finding is supported by Filcheva and Tsadilas (2002), who noted that nutrient retention and availability are key factors in improving crop productivity.

The enhanced nutrient availability observed in this study can be attributed to the unique properties of zeolite. Zeolite's high cation-exchange capacity allows it to adsorb and retain significant amounts of essential nutrients, such as nitrogen and phosphorus, preventing their leaching from the soil. This property ensures that nutrients remain available to plants over an extended period, promoting sustained growth and higher yields.

The substantial increase in nitrate nitrogen levels, particularly in the zeolite 2 t/ha + N90P90K90 treatment, highlights the effectiveness of zeolite in improving nitrogen use efficiency. Nitrogen is a critical nutrient for plant growth, influencing various physiological processes, including chlorophyll synthesis and photosynthesis. By retaining nitrogen in the soil and releasing it gradually, zeolite helps maintain an optimal nitrogen supply, reducing the need for frequent fertilization and minimizing environmental impacts associated with nitrogen leaching. Similarly, the significant increase in mobile phosphorus levels in zeolite-treated soils underscores the importance of phosphorus in root development and energy transfer within plants. Phosphorus is essential for the formation of ATP, which powers various cellular activities. The enhanced availability of phosphorus in the zeolite-treated variants likely contributed to better root growth and overall plant vigor, leading to increased yields. These findings align with previous research by Aainaa et al. (2006) and Mondal et al (2021), who demonstrated that zeolite's ability to retain and slowly release nutrients can significantly improve nutrient use efficiency and crop performance. By enhancing nutrient availability, zeolite not only supports immediate plant growth but also contributes to long-term soil fertility and sustainability.

Table Beet Yield

The application of zeolite and mineral fertilizers had a significant impact on the yield of table beet. The yield data presented in Table 3 demonstrate the positive effects of these treatments on crop productivity. The combined application of zeolite and fertilizers resulted in the highest yield increases.

Table 3. Yield and marketable yield of table beets under different treatments

Treatment	Yield (t/ha)	Marketable Yield (%)
Control	42.8	85.0
Zeolite 2 t/ha	47.2	87.5
N45P45K45	50.3	89.0
N90P90K90	55.8	91.0
Zeolite 2 t/ha + N45P45K45	58.5	92.0
Zeolite 2 t/ha + N90P90K90	62.7	93.5

The yield increase ranged from 4.4 t/ha in the zeolite 2 t/ha treatment to 19.9 t/ha in the zeolite 2 t/ha + N90P90K90 treatment. Marketable yield also improved across all treatments, indicating the positive impact of zeolite and fertilizers on crop quality. These results are consistent with findings by Mumpton (1999), Ippolito et al. (2011), Ozbahce et al. (2015) and Shivakumara et al. (2021), who observed that zeolite application enhances crop yield by improving nutrient availability and soil physical properties. The significant increase in table beet yield and improvement in nutrient availability demonstrate the effectiveness of zeolite as a soil amendment. The combination of zeolite and mineral fertilizers resulted in the highest yield and quality improvements, confirming the synergistic effect of these treatments. Similar findings have been reported by several studies, indicating that zeolite enhances the efficiency of fertilizers, leading to better crop performance (Jarosz et al., 2022).

The significant increase in table beet yield and improvement in nutrient composition demonstrate the effectiveness of zeolite as a soil amendment. The combination of zeolite and mineral fertilizers resulted in the highest yield and quality improvements, confirming the synergistic effect of these treatments. Similar findings have been reported by several studies, indicating that zeolite enhances the efficiency of fertilizers, leading to better crop performance. The application of zeolite in maize cultivation was reported by Malekian et al. (2011) who opined that maize plants resulted in better response to zeolite when used as a fertilizer carrier at the rate of 60 g kg−1 of soil. The application of clinoptilolite zeolite (CZ) with a 75% recommended dose of fertilizer resulted in significantly similar cobs yield in maize as compared to the full recommended dose of fertilizer (Aainaa et al., 2018). The observed yield increases can be attributed to several factors. Zeolite's cation-exchange capacity improves the retention and availability of essential nutrients like nitrogen, phosphorus, and potassium. This ensures a steady supply of nutrients to the plants throughout the growing season, promoting better growth and higher yields. The highest yields were recorded in treatments combining zeolite with N90P90K90, highlighting the synergistic effect of zeolite and higher doses of mineral fertilizers.

In terms of marketable yield, all treatments showed improvements over the control, with the most significant gains seen in the combined treatments of zeolite and fertilizers. This suggests that not only does zeolite improve overall yield, but it also enhances the quality of the produce, making it more marketable. The application of zeolite also contributed to a reduction in nitrate content in the table beet, indicating a safer and more nutritious product. The nitrate content decreased from 350 mg/kg in the control to 240 mg/kg in the zeolite 2 t/ha + N90P90K90 treatment (Table 4). This reduction in nitrate content is crucial as high nitrate levels in vegetables can pose health risks to consumers. Lower nitrate levels in the produce indicate a healthier and safer food product, aligning with consumer demand for higher-quality and safer food options.

Table 4. Nitrate Content, total sugar and dry matter of table beets treated with zeolite and mineral fertilizers

Treatment	Dry Matter (%)	Total Sugar (%)	Nitrate Content (mg/kg)
Control	19.5	8.5	350
Zeolite 2 t/ha	20.1	8.3	320
N45P45K45	20.5	8.2	300
N90P90K90	21.0	8.0	280
Zeolite 2 t/ha + N45P45K45	21.5	7.8	260
Zeolite 2 t/ha + N90P90K90	21.9	7.5	240

Correlation and Regression Analysis

Statistical analysis revealed strong correlations between nutrient availability in the soil and table beet yield. Pearson correlation coefficients were calculated to assess the strength and direction of the relationships between variables. A positive correlation (r = 0.99) was found between nitrate nitrogen content during the germination period and yield. Similarly, mobile phosphorus showed a significant correlation with yield (r = 0.94). These relationships highlight the importance of balanced nutrient management in optimizing crop production.

Linear regression models were developed to predict table beet yield based on significant soil properties and nutrient levels, with equations established to describe these relationships. The following regression equations were determined:

Nitrate Nitrogen and Yield:

$$y=167x_1-0.41x_2-0.29x_3-2.15$$

y: Yield (t/ha)
x1,x2,x3: Nitrate nitrogen content in the 0-20 cm soil layer during the periods of germination, bunching, and technical ripeness (mg/kg of soil).
Correlation coefficient r=0.99, r^2=0.98

Mobile Phosphorus and Yield:

$$y=130x_2+2.17x_3-167x_1-12.9$$

y: Yield of table beet (t/ha)
x1,x2,x3: Mobile phosphorus content in the 0-20 cm soil layer during the periods of germination, bunching, and technical ripeness (mg/kg of soil).
Correlation coefficient r=0.94, r^2=0.88

The results from the correlation and regression analysis underscore the critical role of nutrient availability in determining table beet yield. The strong positive correlation between nitrate nitrogen content and yield (r = 0.99) highlights nitrogen's essential role in promoting vegetative growth and enhancing overall productivity. This finding is consistent with previous research that has demonstrated the importance of nitrogen in supporting plant growth and maximizing yield (Ippolito et al., 2021). The significant correlation between mobile phosphorus and yield (r = 0.94) further emphasizes the importance of phosphorus in root development and energy transfer processes within the plant. Adequate phosphorus availability is crucial during key growth stages to ensure robust root systems and efficient nutrient uptake, ultimately leading to higher yields. The high coefficients of determination (r^2) for the regression models indicate that nitrate nitrogen and mobile phosphorus levels are strong predictors of table beet yield. The regression equations provide valuable insights for developing fertilization strategies that optimize nutrient availability at critical growth stages. For instance, ensuring sufficient nitrate nitrogen during germination and bunching periods can significantly enhance yield, as reflected in the regression model with an r^2 value of 0.98. Similarly, managing mobile phosphorus levels to maintain adequate supply during the technical ripeness stage is vital for maximizing yield potential, as indicated by the regression model with an r^2 value of 0.88. These models demonstrate the significant predictive power of nutrient levels for table beet yield, underscoring the critical role of effective fertilization strategies in achieving high productivity. The strong correlations and high coefficients of determination (r^2) indicate that the regression models accurately represent the relationships between soil nutrients and crop yield. These findings provide a robust framework for optimizing nutrient management practices to enhance table beet productivity, ultimately contributing to sustainable agricultural production systems.

Conclusion

The study demonstrates the significant impact of zeolite and mineral fertilizers on the physical and chemical properties of dark chestnut soil, nutrient availability, and the yield and quality of table beets. The application of zeolite significantly improved soil physical properties, such as water permeability and soil density, which are crucial for root development and plant growth. The enhanced soil structure facilitated better water infiltration and retention, supporting healthier root systems and efficient nutrient uptake. The addition of zeolite and mineral fertilizers notably increased the availability of essential nutrients, particularly nitrate nitrogen and mobile phosphorus. This improved nutrient retention and gradual release ensured a steady supply of nutrients throughout the growing season, leading to higher crop yields. The highest yield increases were observed in treatments combining zeolite with higher doses of mineral fertilizers, highlighting the synergistic effects of these amendments. The correlation and regression analyses revealed strong positive correlations between nutrient availability and table beet yield. The regression models demonstrated the predictive power of nitrate nitrogen and mobile phosphorus levels on crop productivity, emphasizing the critical role of balanced nutrient management in optimizing yield.

Overall, the findings underscore the effectiveness of zeolite as a soil amendment in enhancing soil health, nutrient availability, and crop performance. The combination of zeolite and mineral fertilizers not only improved yield and marketable quality but also reduced nitrate content in table beets, producing a safer and more nutritious product. These results suggest that the use of zeolite in sustainable agricultural practices can contribute to improved crop productivity and food quality. Future research should focus on the long-term effects of zeolite application on soil health and crop performance under various environmental conditions. Additionally, exploring the optimal application rates and methods for different crops and soil types will further validate the benefits of zeolite and enhance its practical implementation in agriculture.

Acknowledgement

This research was supported by the Ministry of Education and Science of the Republic of Kazakhstan under the research grant "AP13068349 Development of methods for increasing the productivity of vegetable crops by using nanomodified zeolite fertilizer in the southeast of Kazakhstan". The authors also wish to thank the anonymous reviewers for their valuable comments and suggestions which helped to improve the quality of this manuscript.

References

Aainaa, H.N., Haruna Ahmed, O., Ab Majid, N.M., Reinhart, K.O., 2018. Effects of clinoptilolite zeolite on phosphorus dynamics and yield of Zea mays L. cultivated on an acid soil. *PLoS ONE* 13 (9): e0204401.

Al-Busaidi, A. Yamamoto, T. Inoue, M. Eneji, A.E. Mori, Y. Irshad, M., 2008. Effects of zeolite on soil nutrients and growth of barley following irrigation with saline water. *Journal of Plant Nutrition* 31(7): 1159-1173.

Baghdadi, A., Halim, R.A., Ghasemzadeh, A., Ramlan, M.F., Sakimin, S.Z., 2018. Impact of organic and inorganic fertilizers on the yield and quality of silage corn intercropped with soybean. *Peer J* 6: e5280.

Barłóg, P., Grzebisz, W., Łukowiak, R., 2022. Fertilizers and fertilization strategies mitigating soil factors constraining efficiency of nitrogen in plant production. *Plants* 11(14): 1855.

Cataldo, E., Salvi, L., Paoli, F., Fucile, M., Masciandaro, G., Manzi, D., Masini, C.M., Mattii, G.B., 2021. Application of zeolites in agriculture and other potential uses: A review. *Agronomy* 11(8): 1547.

Filcheva, E.G., Tsadilas, C.D., 2002.Influence of clinoptilolite and compost on soil properties. *Communications in Soil Science and Plant Analysis* 33 (3-4): 595-607.

Gamage, A., Gangahagedara, R., Gamage, J., Jayasinghe, N., Kodikara, N., Suraweera, P., Merah, O., 2023. Role of organic farming for achieving sustainability in agriculture. *Farming System* 1(1): 100005.

Garbowski, T., Bar-Michalczyk, D., Charazińska, S., Grabowska-Polanowska, B., Kowalczyk, A., Lochyński, P., 2023. An overview of natural soil amendments in agriculture. *Soil and Tillage Research* 225: 105462.

Hazrati, S., Tahmasebi-Sarvestani, Z., Mokhtassi-Bidgoli, A., Modarres-Sanavy, S.A.M., Mohammadi, H., Nicola,S., 2017. Effects of zeolite and water stress on growth, yield and chemical compositions of Aloe vera L. *Agricultural Water Management* 181: 66-72.

Herencia, J.F., Ruiz-Porras, J.C., Melero, S., Garcia-Galavis, P.A., Morillo, E., Maqueda, C., 2007. Comparison between organic and mineral fertilization for soil fertility levels, crop macronutrient concentrations, and yield. *Agronomy Journal* 99(4): 973-983.

Ippolito, J.A., Tarkalson, D.D., Lehrsch, G.A., 2011. Zeolite soil application method affects inorganic nitrogen, moisture, and corn growth. *Soil Science* 176(3):136-142.

Jarosz, R., Szerement, J., Gondek, K., Mierzwa-Hersztek, M., 2022. The use of zeolites as an addition to fertilisers – A review. *Catena* 213: 106125.

Jones, J.B., 2001. Laboratory guide for conducting soil tests and plant analyses. CRC Press, New York, USA. 363p.

Kalra, Y.P., 1997. Handbook of Reference Methods for Plant Analysis. CRC Press, 320p.

Karami, S., Hadi, H., Tajbaksh, M., Modarres-Sanavy, S.A.M., 2020. Effect of zeolite on nitrogen use efficiency and physiological and biomass traits of Amaranth (Amaranthus hypochondriacus) under water-deficit stress conditions. *Journal of Soil Science and Plant Nutrition* 20(3): 1427-1441.

Khan, M., Arif, M., Karim, T., Khan , D., Rashid, H., Ahmad, F., Zeeshan, M., 2022. Food safety and the effect of fertilizers on human health. *International Journal of Endorsing Health Science Research* 11(1): 54–57.

Klute, A.. 1986. Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods, Second Edition. (Ed.). ASA-SSSA, Madison, Wisconsin, USA. 1188p.

Krasilnikov, P., Taboada, M.A., Amanullah, 2022. Fertilizer use, soil health and agricultural sustainability. *Agriculture* 12(4): 462.

Lal, R., Steward, B.A., 2013. Principles of sustainable soil management in agroecosystems. CRC Press. 552p.

Li, Z., Zhang, Y., Li, Y., 2013. Zeolite as slow release fertilizer on spinach yields and quality in a greenhouse test. *Journal of Plant Nutrition* 36(10): 1496-1505.

Malekian, R., Abedi-Koupai, J., Eslamian, S.S., 2011. Influences of clinoptilolite and surfactantmodified clinoptilolite zeolite on nitrate leaching and plant growth. *Journal of Hazardous Materials* 185: 970–976.

Maxotova, A., Nurbayeva, E., Aitbayev, T., Nurgaliyeva, B., 2021. Yield and yield components of five tomato varieties (Solanum lycopersicum) as influenced by chemical NPK fertilizer applications under chestnut soil conditions. *Eurasian Journal of Soil Science* 10(4): 327 - 331.

Mondal, M., Biswas, B., Garai, S., Sarkar, S., Banerjee, H., Brahmachari, K., Bandyopadhyay, P.K., Maitra, S., Brestic, M., Skalicky, M., Ondrisik, P., Hossain, A., 2021. Zeolites enhance soil health, crop productivity and environmental safety. *Agronomy* 11(3): 448.

Mumpton, F.A., 1999. La Roca Magica: Uses of natural zeolites in agriculture and industry. *Proceedings of the National Academy of Sciences (PNAS)* 96: 3463–3470.

Ozbahce, A., Tari, A.F., Gönülal, E., Simsekli, N., Padem, H., 2015. The effect of zeolite applications on yield components and nutrient uptake of common bean under water stress, *Archives of Agronomy and Soil Science* 61(5): 615-626.

Page, A.L., Keeney, D. R., Baker, D.E., Miller, R.H., Ellis, R. Jr., Rhoades, J.D., 1982. Methods of soil analysis, Part 2- Chemical and Microbiological Properties. ASA-SSSA, Madison, Wisconsin, USA. 1159p.

Sadenova, M.A., Abdulina, S.A., Tungatarova, S.A., 2016. The use of natural Kazakhstan zeolites for the development of gas purification catalysts. *Clean Technologies and Environmental Policy* 18: 449–459.

Sankar Ganesh, K., Sundaramoorthy, P., Nagarajan, M., Lawrence Xavier, R., 2017. Role of organic amendments in sustainable agriculture. In: Sustainable Agriculture towards Food Security. Dhanarajan, A. (Ed.). Springer, Singapore. pp 111–124.

Saparov, A., 2014. Soil resources of the Republic of Kazakhstan: Current status, problems and solutions. In: Novel Measurement and Assessment Tools for Monitoring and Management of Land and Water Resources in Agricultural Landscapes of Central Asia. Mueller, L., Saparov, A., Lischeid, G. (Eds.), Environmental Science and Engineering, Springer International Publishing, Switzerland, pp. 61-73.

Sathiyavani, E., Prabaharan N.K., Krishna Surendar, K., 2017. Role of mineral nutrition on root growth of crop plants – A review. *International Journal of Current Microbiology and Applied Sciences* 6(4): 2810-2837.

Shivakumara, M.N., Krishna Murthy, R., Jagadeesha, G.S., 2021. Influence of zeolite application on growth, yield and yield attributes of finger millet (Eleusine Coracana L.) in rainfed condition. *International Journal of Plant and Soil Science* 33(24): 43-58.

Snapp, S., Sapkota, T.B., Chamberlin, J., Cox, C.M., Gameda, S., Jat, M.L., Marenya, P., Mottaleb, K.A., Negra, C., Senthilkumar, K., Sida, T.S., Singh, U., Stewart, Z.P., Tesfaye, K., Govaerts, B., 2023.Spatially differentiated nitrogen supply is key in a global food–fertilizer price crisis. *Nature Sustainability* 6: 1268–1278.

Suieubayeva, S., Denissova, O., Kabdulsharipova, A., Idikut Ozpence, A., 2022. The agricultural sector in the Republic of Kazakhstan: Analysis of the state, problems and ways of solution. *Eurasian Journal of Economic and Business Studies* 66(4): 19–31.

Vassilina, T., Nasiyev, B., Rvaidarova, G., Shibikeyeva, A., Seitkali, N., Salykova, A., Yertayeva, Z., 2023. The effects of clinoptilolite type of zeolite and synthesised zeolite-enriched fertilizer on yield parameters of Cucumber (Cucumis sativus) plant and some chemical properties in dark chestnut soil. *Eurasian Journal of Soil Science* 12(3): 277-281.

Zhaksybayeva, G., Balgabayev, A., Vassilina, T., Shibikeyeva, A., Malimbayeva, A., 2022. Yield of sugar beet and changes in phosphorus fractions in relation to long term P fertilization in chestnut soil of Kazakhstan. *Eurasian Journal of Soil Science* 11(1): 25-32.