Journal of Sohag Agriscience (JSAS) 2025, 10(2): 44-51

ISSN 2735-5578
https://jsasj.journals.ekb.eg
JSAS 2025; 10(2): 44-51

Received: 09 -07-2025
Accepted: 25 -07-2025

Utilizing Nano-Zeolite for Enhancing Some Soil Physical Properties under Sohag Governorate Conditions

Yasser A. M. Hefny, Abdel-rahman A. Mustafa and Eslam M. Mokhtar

Yasser A. M. Hefny
Eslam M. Mokhtar
Agronomy Department
Faculty of Agriculture
Sohag University
Sohag
Egypt

Abdel-rahman A. Mustafa
Soil and water Department
Faculty of Agriculture
Sohag University
Sohag
Egypt

Corresponding author:
Eslam M. Mokhtar
islam1518_2018@agr.sohag.edu.eg

Abstract

This study investigates the impact of nano-zeolite (NZ) applications on key soil physical properties in arid agricultural environments. Soil is a vital component of the biosphere, and enhancing its physical characteristics is critical for sustainable crop production, particularly under drought stress. Nano-zeolites, owing to their high surface area, porosity, and water retention capacity, were evaluated for their effectiveness in improving soil texture, bulk density, porosity, field capacity, wilting point, and available water. The experiments, conducted over two growing seasons, revealed that increasing NZ application significantly reduced soil bulk density and increased total porosity. Additionally, NZ markedly improved soil water retention indicators, including field capacity and available water content, while reducing the wilting point. These improvements enhance soil structure, facilitate root penetration, and support plant growth under water-limited conditions. The results highlight the potential of nano-zeolite as a sustainable soil amendment for improving soil health and water-use efficiency in dryland agriculture.

Keywords: Nano-Zeolite, Soil Physical Properties, Drought, Irrigation, Water retention

INTRODUCTION

Soil is a vital component of the biosphere and is highly susceptible to contamination by heavy metals. In recent years, heavy metal pollution in soils has become a major environmental issue. These metals originate from both natural sources and human activities, including mining, industrial processes, vehicle emissions, agricultural practices such as applying chemical fertilizers and sewage sludge, and the improper disposal of industrial waste (Zhang and Wang, 2020). Due to their non-biodegradable nature and persistence in biological systems, heavy metals are considered one of the most serious environmental pollutants (Khosropour *et al*., 2021). Moreover, the physical characteristics of soil, particularly bulk density and porosity, play a vital role in determining soil structure and plant growth. These properties can be significantly influenced by the addition of nano-zeolites (NZ), which possess a high void volume (~50%) and low density (2.1–2.2 g cm^{-3}), making them efficient soil amendments for improving aeration, moisture retention, and root penetration (Mondal *et al*., 2021). Nano techniques are often utilized in agriculture to increase the quantity and quality of production. Nanotechnology is a fast-growing technology applied at the nanoscale (i.e., about 1 to 100 nanometers) and involves producing and using nanomaterials. In nature, nanomaterials can be generated by biological as well as physical and chemical mechanisms. Nanomaterials with specific physical and chemical properties have tremendous potential in the field of plant sciences (Kumar *et al*., 2023). Nano-zeolites, characterized by their nanoporous aluminosilicate structure (10–100 nm), exhibit high surface area and porosity, enhancing their capacity for water and nutrient retention. Their fine pores generate capillary forces that trap water, allowing gradual release to plant roots during drought, thereby extending irrigation intervals. Additionally, nano-zeolites improve topsoil moisture retention and reduce evaporation by altering soil texture. Their porous structure also acts as a reservoir for essential nutrients (e.g., N, P, K, Ca), enabling slow, efficient nutrient delivery aligned with plant needs. (Mumpton, 1999; Wang *et al*., 2008 and Li *et al*., 2017). Drought is an abiotic stress that is a frequent and recurring aspect of agriculture worldwide. It is believed that nearly a third of the world's territory suffers from a water deficit (Khan *et al*., 2004). The main objective of this study was to evaluate the impact of nano-zeolite application on selected soil physical properties, including water holding capacity, bulk density, particle density, porosity, permanent wilting point, field capacity, and available water.

MATERIALS AND METHODS

1. Site description and procedure

The current study was conducted in the newly reclaimed area of the experimental farm at the Faculty of Agriculture, Sohag University, El-Kawther City, Sohag Governorate, Egypt (Longitude 31°48'1.81"E, Latitude 26°35'27.26"N, and Altitude 220 m). During two successive seasons for the years 2023(1^{st} Season) and 2024(2^{nd} Season), on Gaur plants (*Cyamopsis tetragonoloba* L). Soil samples collected from different field sites were analyzed for their physical and chemical properties by adopting standard procedures and depicted in table (1) and the chemical composition of zeolite after loaded by N in table (2).

Table (1): Physical and chemical analysis of soil.

Soil property	Mean values	References
Soil physical analysis		
Soil texture	Sandy Loam	**Piper (1950).**
Bulk_density Mg m^{-3}	1.66	**Richards (1954).**
Particle density Mg m^{-3}	2.61	**Richards (1954).**
Total porosity %	36.39	**Richards (1954).**
Water holding capacity %	25.2	**Black (1965).**
Field capacity %	9.2	**Black (1965).**
Wilting percentage %	4.1	**Black (1965).**
Available water %	5.1	**Klute (1986).**
Soil chemical analysis		
pH (1:2.5 suspension)	7.7	**McLean (1982).**
EC (dS m^{-1}) (1:5 extract)	1.85	**Jackson (1973).**
OM (%)	0.67	**Walkley and Black (1934).**
Available nitrogen (ppm)	46	**Subbiah and Asija (1956).**
Available phosphorus (ppm)	23	**Olsen *et al*. (1954).**
Available potassium (ppm)	91	**Carson (1980).**

Table (2) Chemical composition of zeolite after loaded by N.

Chemical Composition (%)	**SiO_2**	**TiO_2**	**Al_2O_3**	**Fe_2O_3**	**FeO**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**SrO**	**P_2O_3**	**N**
	45.50	2.81	13.30	5.40	8.31	0.51	6.30	9.52	2.83	0.87	0.22	0.67	2.70
Trace Elements (ppm)	**Ba**	**Co**	**Cr**	**Se**	**Cu**	**Zn**	**Zr**	**Nb**	**Ni**	**Rb**	**Y**		
	10	1.2	35	0.8	19	64	257	13	55	15	22		

2. Field preparation, experimental design, and treatments

The field experiment was conducted over two successive seasons in 2023 and 2024 using a Randomized Complete Block Design (RCBD) in three simple and separate experiments. Each experiment represented a different irrigation interval: (I1) irrigation every 7 days, (I2) irrigation every 10 days, and (I3) irrigation every 14 days. Within each irrigation regime, five fertilizer treatments were applied using three replications. The irrigation water quantity was determined by calculating the discharge of the irrigation canal. Irrigation water applied to the plots at each irrigation was equal to the difference between moisture at the field capacity and the soil moisture content at irrigation time of each irrigation (for each irrigation treatment) plus 10% of the quantity to ensure a good uniform distribution of water through the plots. The quantity of water for each irrigation treatment was computed according to the following formula:

Q = R ×D ×Bd. × (F.C. - S.M.I.)/ 100

Where:

Q = the quantity of water in cubic meter.

R = area that would be irrigated in square meter.

D = the soil depth required to be irrigated in meter.

Bd = bulk density of the soil (gm/ cm^3).

F.C = field capacity of the experimental field in percent.

S.M.I= the soil moisture percentage before irrigation.

Fertilizer treatments were as follows for the next five fertilizer treatments in each experiment

1. (T1)100% of the recommended dose 600g (210kg/fed)nano-zeolite.
2. (T2) 75% of the recommended dose 450g(157kg/fed) nano-zeolite.
3. (T3) 50% of the recommended dose 300g (105kg/fed) nano-zeolite.

4. (T4) 25% of the recommended dose 150g (52kg/fed) nano-zeolite.
5. (T5) Control (recommended dose of mineral NPK fertilization).

The nano-zeolite material was mixed with pure sand at a ratio of 1:50 (nano-zeolite to sand), then added and mixed in the planting furrow within the soil.

3. Soil Analysis after Cultivation

After harvest, soil samples were collected from each plot for physical analysis. The three replicates were thoroughly mixed to form a composite sample, from which a representative subsample was analyzed. Assessed parameters included water holding capacity, bulk density, particle density, porosity, permanent wilting point, field capacity, and available water, using the methods outlined in Table 3.

Table(3) Physical analysis of soil after cultivation

No	Parameter	Methods	Reference
Physical properties			
1	Texture	International pipette method.	**Piper, (1950)**
2	Bulk density (BD)	The undisturbed soil column	**Richards (1954).**
3	Particle density (PD)	Pycnometer method	**Black (1965)**
4	Total porosity (%)	Soil Porosity = **(1 - (BD ÷ PD)) x 100**	**Richards (1954).**
5	Water holding capacity	Box methods	**Keen and Raczkowski (1921)**
6	Field Capacity (FC) (%)	Using pressure membrane equipment	**Black (1965)**
7	Permanent wilting point (PWP) (%)	Using pressure membrane equipment	**Black (1965)**
8	Available water (AW)	AW = FC – PWP	**Black, (1965)**

RESULT AND DISCUSSION

1. Bulk density (BD) and porosity of the soil:

Regarding BD in the current study, the effect of NZ and mineral fertilizers on soil bulk density is presented in table 3. As observed from data, the values of BD ranged from 1.55 to 1.66 g cm^{-3} in the first season and from 1.53 to 1.71 g cm^{-3} in the second season. Generally, the highest values are found in the control treatment while the lowest one found in 100 % treatment. Hence, the BD values decreased with the NZ increased under various irrigation regimes. Porosity is the fraction of the total soil volume occupied by the pore space. Generally, soil porosity is inversely proportional to bulk density. It was observed that the conditioning of soil by NZ provided an increase in total porosity. This obvious from tabulated data in table 3 that showed that the porosity varied from 36.34 to 40.08 % and from 34.27 to 40.96 % in the first and second season, respectively. As a general trend, the minimum values observed under control treatment gradually increased as the addition of NZ doses increased. One of the essential benefits of NZ is its capacity to decrease soil bulk density, which enables higher root penetration and overall soil drainage, thereby increasing plant growth. As is evident from the results of (Pandit *et al.*, 2020) they concluded that applying NZ at rates of 3 to 9 tons per hectare resulting in decreasing in soil bulk density from 1.5 g/cm^3 to as low as 1.02 g/cm^3, therefore enhancing root accessibility and soil structure. Furthermore, NZ enhances soil porosity, which is essential for water retention, drainage, and air exchange. The increased soil porosity improves root respiration and microbial activity and promotes a soil ecosystem. Additionally, NZ facilitates water storage, root penetration, and nutrient uptake while improving soil structure and moisture content, Table (3) Effect of treatments and irrigation levels on bulk density, particle density, total porosity

Irrigation regime	Fertilizer Level	PD (g cm^{-3})		BD (g cm^{-3})		Total porosity%	
		1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
7 days	control	2.62	2.61	1.64	1.69	37.27	35.12
	25	2.60	2.58	1.60	1.59	38.69	38.51
	50	2.58	2.60	1.58	1.59	38.57	38.66
	75	2.60	2.59	1.57	1.55	39.71	40.11
	100	2.59	2.58	1.55	1.54	40.08	40.24
Mean		**2.60**	**2.59**	**1.59**	**1.59**	**38.86**	**38.53**
	control	2.63	2.60	1.67	1.67	36.66	35.95
10 days	25	2.62	2.58	1.60	1.57	38.88	39.12
	50	2.62	2.60	1.58	1.55	39.51	40.29
	75	2.60	2.61	1.57	1.59	39.61	39.19
	100	2.59	2.60	1.56	1.53	39.75	40.96
Mean		**2.61**	**2.60**	**1.60**	**1.58**	**38.88**	**39.10**
	control	2.60	2.60	1.66	1.71	36.34	34.27
14 days	25	2.60	2.61	1.59	1.60	38.82	38.70
	50	2.59	2.61	1.56	1.57	39.88	39.74
	75	2.62	2.59	1.59	1.57	39.35	39.26
	100	2.58	2.60	1.55	1.56	40.04	40.02
Mean		**2.60**	**2.60**	**1.59**	**1.60**	**38.89**	**38.40**
Mean total		**2.60**	**2.60**	**1.59**	**1.59**	**38.88**	**38.68**

essentially supporting plant growth and soil health (Ibrahim and Alghamdi, 2021 and Głąb *et al*., 2021).

2. Soil water characteristics:

The incorporation of NZ into the soil significantly enhances soil water characteristics, including field capacity, wilting point, and available water which are critical for plant growth, especially under water stress conditions. NZ has the ability to increase water retention in soil leading to better moisture availability for plants(Mahmoud *et al*.,2021). Data in table 4 suggested that there was a significant increase in the water content at field capacity (FC) with applying NZ. The highest field capacity value in the first season was 12.83%, while the lowest was 6.85%. Whereas the highest value was 12.31% and the lowest one was 6.82% in the second season. Generally, the lowest values observed in the control treatment, and the values of FC increased as NZ doses increased in all irrigation regimes. Based on the results presented in table 4, the soil water content at the wilting point (WP) ranged from a minimum value of 1.11 to a maximum value of

Table (4) Effect of treatments and irrigation levels on Field capacity, wilting percentage and available water

Irrigation regime	Fertilizer Level	Field capacity(FC%)		Wilting point (WP%)		Available water (AW%)	
		1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
7 days	control	6.85	7.90	1.11	1.22	5.74	6.68
	25	9.52	9.79	1.23	1.51	8.29	8.28
	50	10.44	11.01	1.40	1.90	9.04	9.11
	75	11.91	11.62	2.26	2.00	9.65	9.62
	100	12.41	12.31	2.33	2.13	10.08	10.18
Mean		**10.23**	**10.53**	**1.67**	**1.75**	**8.56**	**8.77**
	control	7.52	8.52	1.22	1.62	6.31	6.91
10 days	25	10.35	10.35	2.30	2.30	8.06	8.06
	50	11.58	11.58	2.47	2.27	9.11	9.31
	75	10.80	11.80	2.11	2.21	8.69	9.59
	100	12.83	12.19	2.82	2.52	10.01	9.67
Mean		**10.62**	**10.89**	**2.18**	**2.18**	**8.44**	**8.71**
	control	6.92	6.82	1.28	1.28	5.63	5.53
14 days	25	9.95	9.96	1.99	1.99	7.96	7.97
	75	10.47	11.00	2.00	2.00	8.47	9.00
	50	10.52	10.72	1.99	1.99	8.54	8.74
	100	11.76	11.98	1.81	2.22	9.95	9.76
Mean		**9.92**	**10.10**	**1.81**	**1.90**	**8.11**	**8.20**
Mean total		**10.25**	**10.50**	**1.89**	**1.94**	**8.37**	**8.56**

2.82% in the first season. While the lowest was 1.22% and the highest value was 2.52 % in the second season. Similarly, as the application of NZ increased the water content at WP increased. Regarding to available water content (AW) of soil, the highest available water content in the first season was 10.08% and the lowest was 5.63% in the second season. Whereas, the highest value was 10.18% and the lowest was 5.53% in the second season. Ibrahim and Alghamdi (2021) reported that adding clinoptilolite zeolite to sandy soils significantly improving the water-holding capacity of the soil. The addition of NZ improves the field capacity, which is the maximum amount of water the soil can hold after excess water has drained. This property is crucial as it ensures that plants have a steady supply of water between irrigation events. Furthermore, NZ helps in improving the available water in the soil, which is the water accessible to plant roots. Mahmoud and Swaefy (2020) noted that nano-zeolite applications have been shown to enhance soil moisture retention, particularly in water-stressed conditions, helping crops withstand periods of drought by maintaining an adequate water supply. In addition to enhancing field capacity, NZ also helps reduce the wilting point, which is the soil moisture content at which plants can no longer extract water. This improvement in moisture retention reduces plant stress during periods of insufficient rainfall or irrigation. The findings of Yilmaz *et al*. (2014) showed that NZ -treated soils exhibited significantly higher water-holding capacities, permanent wilting points, and available water percentages compared to untreated soils. Zeolite's ability to absorb and retain water enhances soil structure and improves the availability of water for plants. Additionally, nano-fertilizers, which incorporate nano-zeolite, have been found to significantly improve soil moisture retention, with some studies indicating that they can increase water retention by 9.3 times compared to conventional fertilizers (Elsabagh *et al*., 2024). This feature is particularly beneficial in sandy soils, which typically have low water retention capacities.

CONCLUSION

Applying nano zeolite (N.Z. 100% concentration) led to a significant improvement in soil physical properties which led to enhance the soil quality and nutrient dynamics under arid conditions. The integrated use of these amendments presents a sustainable strategy to enhance agricultural performance in drylands, especially in the face of climate change and limited water resources. Therefore, we recommend 50% of the NZ dose with irrigation every 14 days.

REFERENCES

Black, C. A. (Ed.). (1965). *Methods of soil analysis* (Agronomy Monograph No. 9). Madison, WI: American Society of Agronomy.

Carson, P. L. (1980). Recommended potassium test. In W. C. Dahnke (Ed.), *Recommended chemical test procedures for the North Central Region* (NCR Publ, *22*, 17-18). North Dakota Agricultural Experimental Station, North Dakota State University.

Dawson, I. G., & Zhang, D. (2024). The 8 billion milestone: Risk perceptions of global population growth among UK and US residents. *Risk Analysis*, *44*(8): 1809-1827.

Elsabagh, A., Ali, M., & Soliman, A. (2024). Effect of nano-zeolite on soil fertility and nutrient availability under different agricultural practices. *Journal of Agricultural Science*, *132*(4): 725-739.

Głąb, T., Gondek, K., & Mierzwa–Hersztek, M. (2021). Biological effects of biochar and zeolite used for remediation of soil contaminated with toxic heavy metals. *Scientific Reports, 11*(1): 6998.

Ibrahim, H. M., & Alghamdi, A. G. (2021). Effect of the particle size of clinoptilolite zeolite on water content and soil water storage in a loamy sand soil. *Water*, *13*(5): 607.

Jackson, M. L. (1973). *Soil chemical analysis*. Englewood Cliffs, NJ: Prentice-Hall.

Khan, I. A., Habib, S. A. J. I. D. A., Sadaqat, H. A., & Tahir, M. H. N. (2004). Selection criteria based on seedling growth parameters in maize varies under normal and water stress conditions. *International Journal of Agriculture and Biology*, 6(2): 252–256.

Khosropour, E., Weisany, W., Tahir, N. A. R., & Hakimi, L. (2021). Vermicompost and biochar can alleviate cadmium stress through minimizing its uptake and optimizing biochemical properties in Berberis integerrima bunge. *Environmental Science and Pollution Research*,1–11.

Klute, A. (1986). Water retention: Laboratory methods. In A. Klute (Ed.), *Methods of soil analysis: Part 1. Physical and mineralogical methods* (2nd ed., Agronomy Monograph No. 9, pp. 635–662). Soil Science Society of America.

Kumar, P., Dhiman, K., Shaunak, I., Gambhir, G., Kumar, A., & Srivastava, D. K. (2023). Nanotechnology applications in agriculture. In *Nanotechnology horizons in food process engineering* (pp. 75-97). Apple Academic Press.

Li, H., Dong, X., da Silva, E. B., de Oliveira, L. M., Chen, Y., & Ma, L. Q. (2017). Mechanisms of metal sorption by biochars: Biochar characteristics and modifications. *Chemosphere*, *178*, 466-478.

Mahmoud, A. W. M and H. M. Swaefy (2020). Comparison between commercial and nano NPK in presence of nano zeolite on sage plant yield and its components under water stress. *Agriculture*, *66*(1): 24-39.

Mahmoud, A. W. M., Hassan, A. Z. A., Mottaleb, S. A., Rowezak, M. M., & Salama, A. M. (2021). The role of nano-silicon and other soil conditioners in improving physiology and yield of drought stressed barley crop. *Agriculture*, *67*(3), 124-143.

McLean, E. O. (1982). Soil pH and lime requirement. In A. L. Page (Ed.), *Methods of soil analysis: Part 2. Chemical and microbiological properties* (2nd ed., Agronomy Monograph No. 9, pp. 199–224).

Mumpton, F. A. (1999). La roca magica: Uses of natural zeolites in agriculture and industry. *Proceedings of the National Academy of Sciences*, *96*(7), 3463–3470.

Olsen, S. R., Cole, C. V., Watanabe, F. S., & Dean, L. A. (1954). *Estimation of available phosphorus in soils by extraction with sodium bicarbonate* (USDA Circular No. 939). Washington, DC: U.S. Department of Agriculture.

Pandit, V. B., Rao, K. J., Naik, M. R., & Sagar, G. C. V. (2020). Effect of different levels of nitrogen and zeolite on soil properties and soil fertility for rice cultivation. *Magnesium*, 15.

Piper, C. S. (1950). *Soil analysis.* Interscience Publishers, Inc.

Richards, L. A. (Ed.). (1954). *Diagnosis and improvement of saline and alkali soils* (USDA Agriculture Handbook No. 60). Washington, DC: U.S. Government Printing Office.

Subbiah, B. V., & Asija, G. L. (1956). A rapid procedure for the estimation of available nitrogen in soils. *Current science*, *25*(8): 259-260.

Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil science*, *37*(1):29-38.

Wang, Y., Li, Y., Fortner, J. D., Hughes, J. B., Abriola, L. M., & Pennell, K. D. (2008). Transport and retention of nanoscale C60 aggregates in water-saturated porous media. *Environmental science & technology*, *42*(10): 3588-3594.

Yilmaz, A., Aydin, S., & Bayram, I. (2014). Effect of zeolite and perlite media on water holding capacity and wilting point in agricultural soils. *Agricultural Sciences, 89*(2): 121-126.

Zhang, Q., & Wang, C. (2020). Natural and human factors affect the distribution of soil heavy metal pollution: A review. *Water, Air, & Soil Pollution*, 231: 1–13.