ISSN: 2538-2152; ECOPERSIA 2026;14(4):345-357.

Zeolite Amendment Enhances Soil Properties, Reduces Irrigation Demand, and Improves Bermudagrass Growth in Arid Sports Field Ecosystems

ARTICLEINFO

Article Type
Original Research

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How to cite this article
Hatib H.M., Abdulaali H.H., Desher M.A. Zeolite Amendment Enhances Soil Properties, Reduces Irrigation Demand, and Improves Bermudagrass Growth in Arid Sports Field Ecosystems. ECOPERSIA 2026;14(4): 345-357.

DOI:
10.48311/ecopersia.2026.122255.82937

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Article History
Received: August 6, 2026
Revised: September 19, 2026
Accepted: September 20, 2026
Published: September 26, 2026

ABSTRACT

Aims: This study evaluated the effects of five Zeolite application rates on soil physical and chemical properties, irrigation water requirements, water use efficiency (WUE), and bermudagrass (*Cynodon dactylon* L.) growth under sports field conditions in southern Iraq.
Materials & Methods: A field experiment was conducted during the winter season of 2026 at Basrah Sports City using five Zeolite rates (0, 5, 10, 15, and 20 t ha^{-1}) in a randomized complete block design (RCBD). We scheduled irrigation using a POGO TurfPro soil-moisture sensor calibrated against the standard gravimetric method to maintain soil moisture at field capacity. We measured soil electrical conductivity (EC), bulk density (BD), applied irrigation water (AIW), plant height (PH), root dry biomass (RDB), relative water content (RWC), shoot dry biomass (SDB), and WUE.
Findings: Zeolite significantly increased EC from 0.35 to 0.46 dS.m^{-1}, while values remained non-saline. At 20 t.ha^{-1} Zeolite application, AIW decreased by 7.2%, whereas PH increased from 17.50 to 21.25 cm (21.42%). RDB increased from 120.53 to 242.45 g.m^{-2} (101.15%), RWC increased from 72.60% to 82.37% (13.46%), and SDB increased from 139.95 to 163.73 g.m^{-2} (16.98%). WUE reached 0.373 g.L^{-1}, a 26.02% improvement over the control.
Conclusion: Zeolite amendment shows promise for improving soil-water management and irrigation efficiency in sandy sports-field soils, particularly when combined with soil-moisture monitoring, while supporting bermudagrass growth in southern Iraq. However, long-term studies are needed to determine optimal application rates and effects on turf quality, costs, and year-round performance.

Keywords: Natural Zeolite; Soil Amendment; Soil Moisture Monitoring; Sports Turf; Water Use Efficiency..

CITATION LINKS

[1] Mumpton, F.A., *La roca magica*: Uses of natural Zeolites in agriculture an... [2] Gholamhoseini M., Ghalavand A., Khodaei-Joghan A., Dolatabadian A., Zakik... [3] Colombani N., Di Giuseppe D., Faccini B., Ferretti G., Mastrocicco M., Co... [4] Belviso C., Satriani A., Lovelli S., Comegna A., Coppola A., Dragonetti ... [5] Satriani A., Belviso C., Lovelli S., Di Prima S., Coppola A., Hassan S.B.... [6] Carrow R.N., Duncan R.R. Best Management Practices for Saline and Sodic T... [7] Braun R.C., Bremer D.J., Ebdon J.S., Fry J.D., Patton A.J. Review of cool... [8] Beard J.B. Turfgrass: Science and Culture 1973; Prentice-Hall. [9] Haghv... [10] Food and Agriculture Organization (FAO). The State of the World's Land an... [11] Intergovernmental Panel on Climate Change (IPCC). Climate Change 2023: Sy... [12] Al-Ansari N. Topography and climate of Iraq. J. Earth Science. Geotechnic... [13] Fereres E., Soriano M.A. Deficit irrigation for reducing agricultural wat... [14] Kisekka I., Peddinti S.R., Kustas W.P., McElrone A.J., Bambach-Ortiz N., ... [15] Negrón-Juárez R., Ferreira S.J., Mota M.C., Faybishenko B., Monteiro M.T.... [16] Datta S., Taghvaeian S. Soil water sensors for irrigation scheduling in t... [17] Magro C., Macolino S., Pornaro C., Segars C.A., McMillan M., Fidanz... [18] Bogena H.R., Weuthen A., Huisman J.A. Recent developments in wireless... [19] Beck H.E., Zimmermann N.E., McVicar T.R., Vergopolan N., Berg A., Woo... [20] Station network. Ministry of Agriculture, Iraq. Available at: Iraqi Agro... [21] Page A.L., Miller R.H., Keeney D.R. Methods of Soil Analysis. Part 2. Che... [22] Bremner J. M., Edwards A.P. Determination and isotope-ratio analysis of d... [23] Jackson M.L. Soil chemical analysis. Verlag: Prentice Hall, Inc., Englewo... [24] Black C.A. Methods of Soil Analysis: Part I, Physical and Mineralogical P... [25] Richards L.A. Diagnosis and improvement of saline and alkali soils. Agric... [26] Grossman R.B., Reinsch T.G. The solid phase, bulk density, and linear ext... [27] Gardner W.H. Water content. Methods of soil analysis: Part 1 Physical and... [28] Barrs H.D., Weatherley P.E. A re-examination of the relative turgidity te... [29] Howell T.A. Enhancing water use efficiency in irrigated agriculture. Agro... [30] Evett S.R., Marek G.W., Colaizzi P.D., Copeland K.S., Ruthardt B.B. Metho... [31] Ramesh K., Biswas A.K., Patra A.K. Zeolitic farming. India. J. Agron. 201... [32] Hosseinalizadeh M., Yeganeh H., Aranian V., Mohammadian Behbahani A., Khe... [33] Jiang J., Chen A., Qi J. Morphophysiological responses and gene regulatio... [34] Whitlark, B. Revised Recommendations for the USGA Method of Putting Green...

Introduction

Natural Zeolite is becoming popular as a soil amendment because it helps soil hold more water. Its porous structure, large surface area, and high cation exchange capacity allow it to keep water and nutrients near plant roots and release them slowly as needed [1,2]. Research shows that adding Zeolite can change soil properties like bulk density, porosity, field capacity, and water availability, and can also reduce water loss from deep drainage and evaporation [3,4]. Zeolite can improve the area around plant roots, help plants use nutrients more efficiently, and reduce the negative effects of salinity and water stress, supporting plant growth and water use [2,5]. These qualities make Zeolite a promising option for sandy soils in sports-turf systems, where keeping enough soil moisture is important for turf growth and performance.

Bermudagrass (*Cynodon dactylon* L.) is a warm-season, perennial turfgrass known for its creeping stolons and rhizomes. Its dense, spreading growth helps it establish quickly and recover from heavy use. This makes it a popular choice for sports fields in warm, dry areas, as it grows fast, tolerates high temperatures, and bounces back well from wear [6,7]. Bermudagrass also stays active in hot weather, which suits sports-turf systems in these climates. In addition, it handles saline soil and irrigation water better than many other turfgrasses [6,8], which is important for sports fields in southern Iraq. Still, keeping bermudagrass healthy in dry areas depends on having enough soil water and good irrigation management [9]. Water shortages are a big challenge for managing sports turf [10,11]. In southern Iraq, especially Basrah Province, high summer temperatures, low rainfall, high evapotranspiration, and salty soils and water can quickly dry out the soil and increase irrigation needs [12]. In these conditions, it is important to help the root zone hold more water and to use irrigation based on real soil moisture levels to avoid wasting water and keep the turf healthy [10,13,14].

Zeolite can help in these systems by improving soil water-holding capacity and changing the environment around plant roots. By affecting water availability and the physical state of the root zone, Zeolite can create better conditions for root growth and help plants take up and retain more nutrients [3,5]. Better soil-water conditions can support plant growth and help plants use irrigation water more efficiently. However, the extent of these benefits depends on Zeolite application rate, soil type, climate, and irrigation management.

Soil-moisture sensors are a practical way to check soil water levels and help schedule irrigation based on real measurements instead of guesses [15,16]. The portable POGO TurfPro sensor quickly measures soil water content without damaging it, which helps manage turfgrass [17]. However, sensor readings can vary with soil texture, bulk density, salinity, and organic matter [18]. So, calibrate the sensor using a standard gravimetric method for the specific soil to get accurate moisture readings before using it for irrigation scheduling [15,18].

Previous studies have examined how Zeolite affects soil and plant water use and how soil-moisture sensors support irrigation. However, field data on how bermudagrass in sandy sports-field soil responds to different amounts of Zeolite under locally calibrated soil-moisture irrigation management remain limited, especially in southern Iraq's hot, dry climate. More research is also needed to understand how different Zeolite rates affect soil salinity, soil properties, irrigation needs, bermudagrass growth, and water-use efficiency in these conditions [3,4].

This study examined how bermudagrass responds to different amounts of Zeolite in sandy sports-field soil, using irrigation managed with a locally calibrated POGO soil-moisture sensor. The research looked at how Zeolite affects soil electrical conductivity, bulk density, irrigation needs, shoot and root growth, and water-use efficiency. The hypothesis was that Zeolite application would improve soil-water conditions, reduce irrigation needs, support bermudagrass growth, and increase water-use efficiency under sports-field conditions.

Materials & Methods

Study Site

The field experiment was conducted during the winter growing season of 2026 at a Basrah Sports City located in Basrah Province, southern Iraq (30.44147° N, 47.77884° E). According to the Köppen Geiger climate classification [19], the study area is characterized by a hot desert climate (BWh), with extremely hot summers, mild winters, low annual precipitation, and high evaporation levels, making irrigation management a major challenge for preserving high-quality sports turf (Table 1)[20].

Soil and Irrigation Water Sampling and Analyses

We collected composite soil samples from the 0–10 cm surface layer before the experiment. We air-dried the samples, crushed them, and passed them through a 2-mm sieve before physical and chemical analyses. Soil pH, electrical conductivity (EC), organic matter, available potassium, available phosphorus [21], available nitrogen [22], total calcium carbonate [23], bulk density, particle-size distribution (sand, silt, and clay), and field capacity [24] were determined using standard laboratory procedures. Adding peat moss at 20 $L.m^{-2}$ during root-zone preparation affected both bulk density and field capacity. This treatment can lower bulk density and help sandy soil hold more water. Table 2 presents the initial physical and chemical properties of the experimental soil and the main characteristics of the irrigation water.

Zeolite Treatments

We incorporated Zeolite into the top 10 cm of soil before planting at application rates of 0, 5, 10, 15, and 20 $t.ha^{-1}$ based on soil dry weight. These were symbolized as Z0, Z1, Z2, Z3, and Z4, respectively, to ensure uniform distribution within the root zone. The Zeolite's chemical and mineralogical composition was as follows: it was rich in Silicon dioxide (SiO_2) and Aluminum oxide (Al_2O_3), along with several other metal oxides. The predominant minerals were Phillipsite, Augite, Anorthite, and Anorthoclase, with Chabazite and Hematite as minor minerals. Albite and Calcite occurred in minor quantities. Jordan's Directorate of Laboratories and Quality at the Ministry of Energy and Mineral Resources determined the chemical composition of the Zeolite used in this experiment. Table 3 lists the Zeolite's chemical and mineralogical properties.

Bermudagrass Establishment

The experiment used Bermudagrass (*Cynodon dactylon* L.). We prepared plots using standard turfgrass management methods, as described by Whitlark (2018). We applied Zeolite to all treatments at the specified rates, except the control, which received none. Each plot measured 2 by 2 m (4 m^2) and had a 1-meter buffer between them. Within each replication, plots were arranged in rows. The Sports City system supplied irrigation water with salinity below 0.5 dS.m^{-1}. We kept all cultural practices consistent during the experiment.

Calibration of the POGO Soil Moisture Sensor

Before irrigation scheduling, we calibrated the POGO TurfPro soil moisture sensor, which measures volumetric water content using coaxial impedance dielectric permittivity technology, against the standard gravimetric method under experimental soil conditions [17]. We used soil samples with a wide range of moisture contents and measured volumetric water content with the POGO sensor. We determined the corresponding gravimetric water content by oven-drying the samples at 105 ± 2°C to a constant weight, then converted the results to volumetric water content using the soil bulk density. We performed linear regression analysis to establish the calibration equation relating POGO readings to the reference measurements. We then used the resulting calibration equation throughout the irrigation management program. Figure 1 presents the calibration curve.

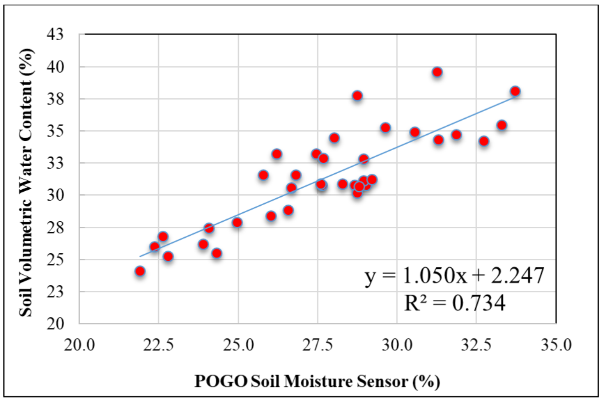

Figure 1) Calibration curve of the POGO soil moisture sensor against the standard gravimetric method.

Irrigation Management

We managed irrigation according to soil field capacity rather than fixed irrigation intervals. We determined field capacity separately for each Zeolite treatment before the main experiment using independent 2×2 m plots. We saturated each plot with water, covered it for 24 h to minimize evaporation and allow gravitational drainage, and then sampled it for gravimetric soil moisture determination. We used the measured moisture content as the field capacity for each treatment. Throughout the experiment, we periodically monitored soil moisture using the calibrated POGO soil moisture sensor. When soil moisture fell below field capacity, we irrigated to restore it. We measured the irrigation water applied to each experimental unit using a water flow meter installed on the irrigation line.

Measurements

At the end of the growing period (fourth month), we performed soil and plant measurements to evaluate the effects of the different Zeolite treatments. We determined soil electrical conductivity (EC) in a 1:1 soil-to-water extract [25] using an EC meter and expressed it as dS.m^{-1}. We measured soil bulk density using the core sampling method [26] after oven-drying undisturbed soil cores at 105 ± 2°C [27] to constant weight. We determined plant shoot dry biomass on three sampling dates (the second, third, and fourth months) by harvesting the shoots and oven-drying them at 70°C to constant weight. We carefully excavated and washed root systems, then oven-dried them at 70°C to constant weight to determine root dry biomass. We determined leaf relative water content (RWC) at the end of the growing period to assess bermudagrass leaf water status. We weighed fresh leaf samples immediately (fresh weight), then immersed them in distilled water for 4–6 h in darkness and gently blotted them before weighing to obtain the turgid weight. We then oven-dried the samples at 70°C to constant weight to determine dry weight [28].

Table 1) Meteorological conditions recorded over ten days during the experiment.

Period	Mean Temperature (°C)	Minimum Temperature (°C)	Maximum Temperature (°C)	Rainfall (mm)	Evaporation (mm)
1–10 January	11.81	4.60	19.03	0.00	3.26
11–20 January	11.22	4.81	17.62	0.00	2.99
21–31 January	11.80	6.14	17.45	3.54	2.58
1–10 February	16.85	10.72	22.98	0.84	2.76
11–20 February	20.36	13.39	27.32	0.04	4.19
21–28 February	19.31	11.16	27.46	0.00	5.00
1–10 March	15.46	8.19	22.73	0.16	5.20
11–20 March	18.70	13.35	24.05	3.51	3.92
21–31 March	19.08	14.11	24.05	2.75	3.76
1–10 April	21.00	14.24	27.41	0.60	4.79
11–20 April	23.88	16.62	30.71	0.84	5.85
21–30 April	24.91	18.47	31.71	4.28	5.68

We recorded the cumulative irrigation water applied to each experimental unit using a water flow meter throughout the growing period. We calculated water use efficiency (WUE) as the ratio of dry biomass of aerial parts to total irrigation water used per month, expressed in $g.L^{-1}$ [29].

Statistical Analysis

We analyzed data using analysis of variance (ANOVA) for a Randomized Complete Block Design (RCBD). We assessed the normality of the ANOVA residuals using the Shapiro–Wilk test. We compared treatment means using the Revised Least Significant Difference (RLSD) test at the 5% probability level ($P \leq 0.05$). We performed statistical analyses using SPSS version 26.

Findings

Soil Electrical Conductivity (EC)

Soil electrical conductivity (EC) increased significantly with increasing Zeolite application (Figure 2). The EC values were 0.35, 0.37, 0.38, 0.40, and 0.46 $dS.m^{-1}$ for Z0, Z1, Z2, Z3, and Z4, respectively. Thus, EC increased progressively with increasing Zeolite rate, with the highest value recorded at 20 t ha^{-1} (Z4), representing an increase of approximately 31.4% compared with the control treatment (Z0).

Figure 2) Effect of Zeolite application levels on soil electrical conductivity (EC).

Table 2) Initial physical and chemical properties of the experimental soil and characteristics of the irrigation water used in the experiment.

Property	Soil	Irrigation Water	Unit
pH	7.72	8.20	---
EC	1.68	0.46	$dS.m^{-1}$
Available Nitrogen	24.5	---	$mg.Kg^{-1}$
Available Potassium	60.5	---	$mg.Kg^{-1}$
Available Phosphorus	4.53	---	$mg.Kg^{-1}$
Organic Matter	3.6	---	$g.Kg^{-1}$
Field Capacity	22	---	%
Total Calcium Carbonate	110.9	---	$g.Kg^{-1}$
Bulk Density	1.45	---	$Mg.m^{-3}$
Sand	889.6	---	$g.Kg^{-1}$
Clay	55.2	---	$g.Kg^{-1}$
Silt	55.2	---	$g.Kg^{-1}$

Note: Values represent measurements obtained before the experiment. We determined EC using a 1:1 (soil:water) extract [21].

Table 3) Chemical composition, physicochemical properties, and mineralogical characteristics of the Zeolite used in this study.

Chemical Composition		Physical and Chemical Properties		Mineralogical Composition		
Property	**Value (wt.%)**	**Property**	**Value**	**Major Minerals**	**Secondary Minerals**	**Minor Minerals**
SiO_2	42.45	CE	7.79 $dS.m^{-1}$	Phillipsite, Augite, Anorthite, Anorthoclase	Chabazite, Hematite	Albite, Calcite
Fe_2O_3	13.90	pH	7.20			
Al_2O_3	13.55	Bulk Density	1.30 $Mg.m^{-3}$			
CaO	9.90	Available Nitrogen	94.5 $mg.Kg^{-1}$			
MgO	8.64	Available Potassium	536.8 $mg.Kg^{-1}$			
TiO_2	3.43					
Na_2O	3.18					
K_2O	1.59					
P_2O_5	0.45					
MnO	0.14					

Bulk Density

Bulk density decreased progressively with increasing Zeolite application (Figure 3). The control treatment recorded the highest bulk density (1.44 $Mg.m^{-3}$), whereas the highest Zeolite application rate (Z4) reduced bulk density to 1.33 $Mg.m^{-3}$, representing a reduction of approximately 7.63%.

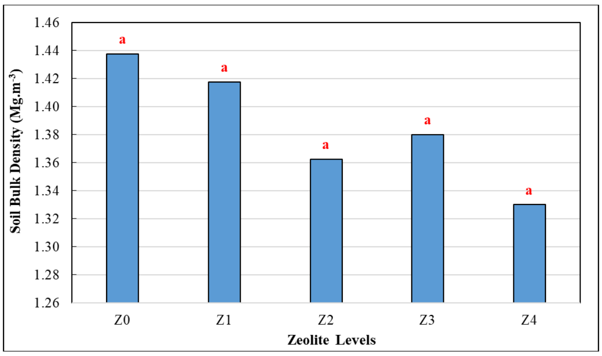

Figure 3) Effect of different Zeolite application levels on soil bulk density.

Applied Irrigation Water

The cumulative amount of irrigation water required to maintain soil moisture at field capacity decreased consistently with increasing Zeolite application throughout the experimental period (Table 4). The highest Zeolite treatment (Z4) required the least irrigation water and reduced cumulative irrigation water application by 7.20% compared with the control treatment.

Table 4) Effect of different Zeolite application levels on cumulative applied irrigation water (L) during the experimental period.

Zeolite Treatments	February 1,2026	March 1, 2026	April 1, 2026
Z0	930.27[a]	1642.95[a]	1891.29[a]
Z1	915.06[a]	1620.49[a]	1864.86[ab]
Z2	892.10[b]	1561.40[b]	1819.15[bc]
Z3	879.05[b]	1524.06[b]	1788.30[cd]
Z4	847.49[c]	1450.27[c]	1755.69[d]
$RLSD_{0.05}$	17.56	43.52	61.43

Note: Means with different superscript letters are significantly different based on the Revised Least Significant Difference (RLSD) test at $P \leq 0.05$.

Plant Height

Plant height increased with increasing Zeolite application (Figure 4). Measured heights were 17.50, 18.25, 19.50, 20.75, and 21.25 cm for Z0, Z1, Z2, Z3, and Z4, respectively. The tallest plants grew with the highest Zeolite rate (Z4, 20 $t.ha^{-1}$), reaching 21.25 cm, while the control group (Z0) reached 17.50 cm. This is about a 21.42% increase.

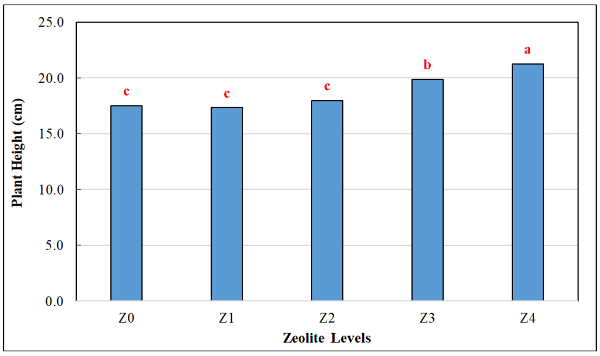

Figure 4) Effect of different Zeolite application levels on bermudagrass plant height.

Root Dry Biomass

Root dry biomass increased with increasing Zeolite application (see Figure 5). The values were 120.53, 134.72, 172.86, 210.34, and 242.45 g m^{-2} for Z0, Z1, Z2, Z3, and Z4. The highest biomass was found at the highest Zeolite rate (Z4, 20 t ha^{-1}), reaching 242.45 g m^{-2}. This is about 101.15% higher than the control (Z0), which had 120.53 g m^{-2}.

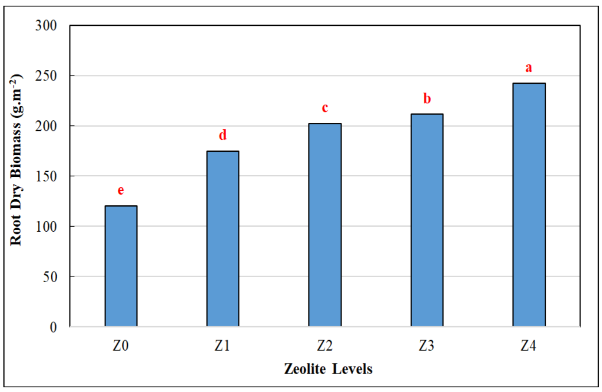

Figure 5) Effect of different Zeolite application levels on bermudagrass root dry biomass.

Leaf Relative Water Content (RWC)

Leaf relative water content (RWC) increased with increasing Zeolite application (Figure 6). The control treatment (Z0) had the lowest RWC at 72.60%, while the highest was in the Z4 treatment (20 t ha^{-1}) at 82.37%. This was about 13.46% higher than the control. The intermediate treatments, Z1, Z2, and Z3, had RWC values of 76.10%, 77.68%, and 79.78%, respectively (Figure 6).

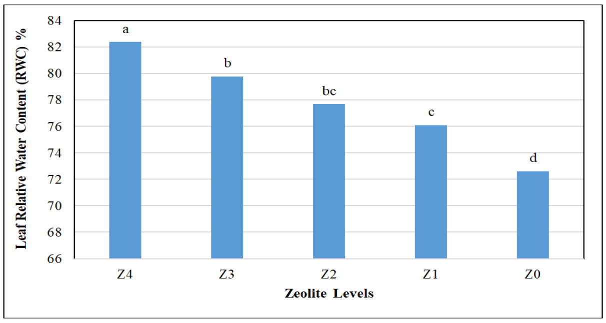

Figure 6) The effect of various Zeolite application levels on the relative water content (RWC%) of bermudagrass leaves.

Shoot Dry Biomass

Shoot dry biomass increased progressively with increasing Zeolite application throughout the growing period (Table 5). At the end of the experiment, the highest shoot dry biomass (163.73 $g.m^{-2}$) was recorded in the highest Zeolite treatment (Z4). In contrast, the control treatment produced 139.95 $g.m^{-2}$, corresponding to an increase of approximately 16.98%.

Table 5) Effect of different Zeolite application levels on bermudagrass shoot dry biomass ($g.m^{-2}$) during the experimental period.

Zeolite Treatments	February 1, 2026	March 1, 2026	April 1, 2026
Z0	0.752^{d}	2.239^{d}	139.953^{d}
Z1	0.762^{d}	2.660^{c}	144.520^{c}
Z2	0.942^{c}	2.793^{c}	159.505^{b}
Z3	1.051^{b}	3.061^{b}	160.183^{b}
Z4	1.132^{a}	3.259^{a}	163.729^{a}
$RLSD_{0.05}$	0.069	0.139	1.890

Note: Means with different superscript letters are significantly different based on the Revised Least Significant Difference (RLSD) test at $P \leq 0.05$.

Water Use Efficiency

Water use efficiency (WUE) increased consistently with increasing Zeolite application throughout the experimental period (Table 4). The highest WUE (0.373 $g.L^{-1}$) was observed in the highest Zeolite treatment (Z4), representing an improvement of approximately 26.02% over the control treatment (Table 6).

Table 6) Effect of different Zeolite application rates on water-use efficiency (WUE) ($g.L^{-1}$) during the experimental period.

Zeolite Treatments	February 1, 2026	March 1, 2026	April 1, 2026
Z0	0.0032^{d}	0.0055^{c}	0.2960^{c}
Z1	0.0033^{d}	0.0067^{bc}	0.3100^{c}
Z2	0.0042^{c}	0.0072^{abc}	0.3507^{b}
Z3	0.0048^{b}	0.0080^{ab}	0.3583^{ab}
Z4	0.0053^{a}	0.0090^{a}	0.3730^{a}
$RLSD_{0.05}$	0.0004	0.0019	0.0155

Note: Means with different superscript letters are significantly different based on the Revised Least Significant Difference (RLSD) test at $P \leq 0.05$.

Discussion

Effect of Zeolite on Soil Properties

Applying Zeolite improved the physical properties of the sandy soil by reducing bulk density, with only a slight increase in soil electrical conductivity (EC). The gradual increase in EC with increasing Zeolite application can be attributed to the release of exchangeable cations, particularly Ca^{2+}, K^{+}, Na^{+}, and Mg^{2+}, naturally present within the Zeolite structure [1,2]. In addition, Zeolite's high water-holding capacity may reduce salt leaching, resulting in a moderate accumulation of soluble ions within the root zone [4]. Nevertheless, all measured EC values remained within the non-saline range, indicating that Zeolite application improved soil water retention without adversely affecting soil salinity.

The reduction in bulk density is primarily associated with the porous structure and relatively low particle density of natural Zeolite, which increased soil porosity and improved soil aggregation. Although the reduction in bulk density was not statistically significant during the experimental period, it indicates improved soil physical conditions. Adding Zeolite particles to the large pores between sand particles increases soil porosity, explaining the decrease in apparent density and improved soil physical conditions, thereby creating more favorable conditions for root nutrient uptake. Ramesh et al. (2015) and Colombani et al. (2016) reported similar improvements in soil physical quality following Zeolite incorporation, while Belviso et al. (2022) and Satriani et al. (2024) also observed comparable reductions in bulk density in sandy soils.

Effect of Zeolite on Irrigation Water Requirements

Increasing Zeolite application consistently reduced the amount of irrigation water required to maintain soil moisture at field capacity [2]. This reduction can be attributed to Zeolite's exceptional water-retention capacity, which arises from its highly porous crystalline structure and allows it to store considerable quantities of water and release them gradually into the surrounding soil. Consequently, soil moisture remained closer to field capacity for longer periods, extending the interval between irrigation events [5].

A locally calibrated POGO soil moisture sensor further improved irrigation management by allowing irrigation only when soil moisture fell below field capacity and replenishing it based on actual soil water status. This precision irrigation approach minimized unnecessary water application and clearly demonstrated Zeolite's benefit for irrigation water conservation [15,30]. These findings agree with Colombani et al. (2016), who reported that Zeolite improves soil hydraulic behavior and irrigation efficiency, and with Satriani et al. (2024), who showed that Zeolite amendments increase plant-available water and improve soil water retention characteristics.

Effect of Zeolite on Bermudagrass Growth

Changes in shoot dry biomass across sampling dates may reflect early-season temperature conditions. The low temperatures in the first months (Table 1) probably slowed bermudagrass growth, since it is a warm-season species. When temperatures rose later in the growing period, shoot biomass production also increased.

The improvements observed in plant height, root dry biomass, and shoot dry biomass indicate that Zeolite created a more favorable root-zone environment for bermudagrass growth. Improved soil water availability maintained higher cell turgor and photosynthetic activity, thereby supporting sustained shoot growth under water-limited conditions [4,9]. By increasing soil water retention, Zeolite reduced plant water stress between irrigation events and promoted continuous cell division and vegetative development [4]. Improved soil aeration and reduced bulk density also enhanced root activity and nutrient acquisition, contributing to greater aboveground growth [3,5]. Similar improvements in bermudagrass growth following Zeolite application under water-limited conditions have been previously reported [2].

Root development responded particularly well to Zeolite incorporation. Lower soil bulk density and greater soil porosity reduced mechanical resistance to root penetration, while improved soil moisture retention ensured a more stable water supply within the root zone [3,5]. The resulting increase in root biomass enhanced bermudagrass's capacity to absorb water and nutrients and improved its tolerance to drought stress, contributing to the observed increases in shoot growth and biomass production. Comparable improvements in root development following Zeolite application have been reported for coarse-textured soils [4].

Similarly, the progressive increase in shoot dry biomass reflected the combined effects of enhanced soil moisture retention, improved nutrient availability, and better root development [2,5]. By maintaining more favorable soil water conditions, Zeolite supported higher photosynthetic activity and greater biomass accumulation throughout the growing season [31,32]. The increasing response over time suggests that Zeolite's beneficial effects became more pronounced as soil physical conditions gradually improved. Several crops have shown similar increases in biomass production after Zeolite application due to improved soil physical properties and water availability [4].

Effect of Zeolite on Bermudagrass Growth and Water Status

As Zeolite application increased, bermudagrass leaf relative water content (RWC) also rose, suggesting improved water status. In the control group, RWC was 72.60%; at the highest Zeolite rate (20 t ha^{-1}), it reached 82.37%, an increase of 13.46% (Figure 6). Zeolite may have produced this effect by retaining water in the root zone and supplying it more steadily between irrigations. The resulting increase in RWC likely contributed to the greater plant height and root and shoot dry biomass. Jiang et al. (2025) identified RWC as a key indicator of bermudagrass water status and reported that drought-tolerant bermudagrass maintains higher RWC under water stress. In this study, the higher RWC measured with Zeolite offers stronger physiological evidence that, under these conditions, Zeolite improves bermudagrass water status.

Effect of Zeolite on Water Use Efficiency

Water use efficiency (WUE) improved consistently with increasing Zeolite application because shoot biomass increased while irrigation water requirements decreased. Improved soil water retention enabled bermudagrass to produce greater biomass using less irrigation water [2]. In contrast, POGO sensor-based irrigation scheduling minimized unnecessary irrigation losses by applying water according to actual soil moisture conditions [15,30]. Together, these factors substantially improved irrigation efficiency and water productivity under the hot, arid conditions of southern Iraq.

The increase in WUE observed in this study is consistent with previous research showing that Zeolite can enhance soil water retention and improve water-use-related performance. In the present study, applying the highest Zeolite rate (20 t ha^{-1}) increased WUE by 26.02% compared with the control and reduced cumulative irrigation water application by 7.20% (Table 6). Colombani et al. (2016) reported that natural Zeolite amendment increased soil water availability in a two-year field experiment, with residual water content increasing by 1.2 ± 0.4% during summer droughts and water losses decreasing after rainfall. Gholamhoseini et al. (2013) also reported higher irrigation water productivity in sandy soil, reaching 0.81 kg

m^{-3} under limited irrigation with the highest Zeolite-containing treatment, compared with 0.48 kg m^{-3} in the comparison treatment. More recently, Satriani et al. (2024) showed that Zeolite amendment modified soil water-retention behavior and improved soil physical properties, particularly in coarse-textured soils. Belviso et al. (2022) similarly reported improvements in soil hydrological properties following Zeolite application. These findings support Zeolite's role in improving soil water availability and water-use performance. However, make direct comparisons across studies cautiously because of differences in soil texture, Zeolite type and application rate, crop species, irrigation regime, and calculation methods. The economic value of Zeolite use depends on its price, the application rate, field size, and possible savings from reduced irrigation and improved turfgrass performance. This study did not include a full economic analysis, but the lower irrigation requirements observed at higher Zeolite rates point to potential economic benefits that warrant evaluation in local markets. Zeolite is a natural mineral amendment; however, its long-term environmental effects depend on its mineral and chemical composition and the quantity applied. Long-term field studies are needed to determine its economic value and environmental safety under local conditions.

Conclusion

This study found that applying Zeolite improved the physical and water-related properties of sandy soil used for sports turf. As the application rate increased, soil bulk density fell and water retention improved. Irrigation needs therefore declined, while bermudagrass growth and water use efficiency improved. Soil electrical conductivity rose slightly at higher Zeolite levels, but every measured value remained within the non-saline range, with no adverse effect on plant growth. Irrigation scheduling based on a POGO soil moisture sensor, calibrated using the gravimetric method, also accurately and reliably tracked soil moisture and allowed irrigation to be applied according to the soil's actual water status. Using Zeolite as a soil amendment alongside sensor-based precision irrigation offers an effective way to reduce irrigation water consumption while maintaining high-quality sports turf in the hot, arid conditions of southern Iraq. Future studies should examine Zeolite's long-term effects under varying irrigation water qualities and environmental conditions to support more sustainable turfgrass management.

Acknowledgments

The authors thank Mawarid Al-Tabiah Company for Trading and Manufacturing Agricultural Supplies for providing the natural Zeolite and its available technical and analytical information used in this study. The authors also appreciate the company's support and cooperation.

Authors' Contributions: All authors contributed to planning, designing, and conducting the study. **H.M Hatib:** Led the statistical analysis and interpreted the data. **H.H Abdulaali:** Handled field equipment calibration and operation, checked data quality, and helped with data collection and manuscript writing. **M.A Desher:** Joined the field experiment, collected samples, and organized the data. All authors helped interpret the data, reviewed the manuscript for key content, approved the final version, and accepted responsibility for the work. **Ethical Permission:** This study did not require ethical approval because it was a field experiment on bermudagrass and did not involve people, animals, or activities requiring ethical review.

Funding/ Support: The authors declare that they received no funds, grants, or other support during the preparation of this manuscript.

Conflict of interest: The authors declare no relevant financial or non-financial conflicts of interest.

AI Use Declaration: The authors used Grammarly only to edit language and improve grammar, spelling, punctuation, and clarity in the manuscript. They did not use any generative artificial intelligence (AI) tools to create, analyze, interpret, or change the research data, results, or scientific conclusions. The authors take full responsibility for the manuscript's accuracy, originality, and integrity.

References

1. Mumpton, F.A., *La roca magica*: Uses of natural Zeolites in agriculture and industry. Proc. Natl. Acad. Sci., 1999; 96(7):3463-3470.
2. Gholamhoseini M., Ghalavand A., Khodaei-Joghan A., Dolatabadian A., Zakikhani H., Farmanbar E. Zeolite-amended cattle manure effects on sunflower yield, seed quality, water use efficiency and nutrient leaching. Soil Till. Res. 2013; 126(1):193-202.
3. Colombani N., Di Giuseppe D., Faccini B., Ferretti G., Mastrocicco M., Coltorti M. Estimated water savings in an agricultural field amended with natural Zeolites. Environ. Process. 2016; 3(3):617-628.
4. Belviso C., Satriani A., Lovelli S., Comegna A., Coppola A., Dragonetti G., Rivelli A.R. Impact of Zeolite from coal fly ash on soil hydrophysical properties and plant growth. Agriculture. 2022; 12(3):356.
5. Satriani A., Belviso C., Lovelli S., Di Prima S., Coppola A., Hassan S.B., Comegna A. Impact of a synthetic Zeolite mixed with soils of different pedological characteristics on soil physical quality indices. Geoderma 2024; 451: 117084.
6. Carrow R.N., Duncan R.R. Best Management Practices for Saline and Sodic Turfgrass Soils. CRC Press, Taylor & Francis Group, Boca Raton. 2012:415p.
7. Braun R.C., Bremer D.J., Ebdon J.S., Fry J.D., Patton A.J. Review of cool-season turfgrass water use and requirements: I. Evapotranspiration and responses to deficit irrigation. Crop Sci. 2022; 62(5)1661-1684:.
8. Beard J.B. Turfgrass: Science and Culture 1973; Prentice-Hall. 658p.
9. Haghverdi A., Singh A., Sapkota A., Reiter M., Ghodsi S. Developing irrigation water conservation strategies for hybrid bermudagrass using an evapotranspiration-based smart irrigation controller in inland southern California. Agric. Water Manag. 2021; 245: 106586.
10. Food and Agriculture Organization (FAO). The State of the World's Land and Water Resources for Food and Agriculture Systems at Breaking Point 2023; Rome, Italy: FAO.
11. Intergovernmental Panel on Climate Change (IPCC). Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change 2023; Geneva, Switzerland: IPCC. 3-32.
12. Al-Ansari N. Topography and climate of Iraq. J. Earth Science. Geotechnic. Engineer. 2021; 11(2):1-13.
13. Fereres E., Soriano M.A. Deficit irrigation for reducing agricultural water use. J. Exp. Bot. 2007; 58(2):147-159.
14. Kisekka I., Peddinti S.R., Kustas W.P., McElrone A.J., Bambach-Ortiz N., McKee L., Bastiaanssen W. Spatial–temporal modeling of root zone soil moisture dynamics in a vineyard using machine learning and remote sensing. Irrig. Sci. 2022; 40(4):761-777.
15. Negrón-Juárez R., Ferreira S.J., Mota M.C., Faybishenko B., Monteiro M.T.F., Candido L.A., Chambers J.Q. Calibration, measurement, and characterization of soil moisture dynamics in a central Amazonian tropical forest. Vadose Zone J. 2020; 19(1):e20070.
16. Datta S., Taghvaeian S. Soil water sensors for irrigation scheduling in the United States: A systematic review of literature. Agric. Water Manag. 2023; 278: 108148.
17. Magro C., Macolino S., Pornaro C., Segars C.A., McMillan M., Fidanza M. Monitoring trends of volumetric water content in turfgrass root-zones with a soil moisture meter from 2014 to 2021. Agrosystems Geosci. Environ. 2026; 9(2):e70373.
18. Bogena H.R., Weuthen A., Huisman J.A. Recent developments in wireless soil moisture sensing to support scientific research and agricultural management. Sensors 2022; 22(24):9792.
19. Beck H.E., Zimmermann N.E., McVicar T.R.,

Vergopolan N., Berg A., Wood E.F. Present and future Köppen-Geiger climate classification maps at 1-km resolution. Sci. Data 2018; 5(1):180214.
20. Station network. Ministry of Agriculture, Iraq. Available at: Iraqi Agrometeorological Centre. Accessed August 2026.
21. Page A.L., Miller R.H., Keeney D.R. Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. American Society of Agronomy. In Soil Science Society of America 1982;1159p.
22. Bremner J. M., Edwards A.P. Determination and isotope-ratio analysis of different forms of nitrogen in soils: I. Apparatus and procedure for distillation and determination of ammonium. Soil Sci. Soc. Am. 1965; 29(5):504-507.
23. Jackson M.L. Soil chemical analysis. Verlag: Prentice Hall, Inc., Englewood Cliffs, NJ. 1958, 498 S. DM 39.40. J. Soil Sci. 1962; 9(6):251-252.
24. Black C.A. Methods of Soil Analysis: Part I, Physical and Mineralogical Properties. American Society of Agronomy Madison, Wisconsin. America. J. Plant Sci.1965; 1-27.
25. Richards L.A. Diagnosis and improvement of saline and alkali soils. Agriculture Handbook 1958;60(1):210-220.
26. Grossman R.B., Reinsch T.G. The solid phase, bulk density, and linear extensibility. Methods of soil analysis 2002; Part 4: 201-228.
27. Gardner W.H. Water content. Methods of soil analysis: Part 1 Physical and Mineralogical Methods.1986;5(1):493-544.
28. Barrs H.D., Weatherley P.E. A re-examination of the relative turgidity technique for estimating water deficits in leaves. J. Biol. Sci. 1962;15(3):413-428.
29. Howell T.A. Enhancing water use efficiency in irrigated agriculture. Agron. J. 2001; 93(2):281-289.
30. Evett S.R., Marek G.W., Colaizzi P.D., Copeland K.S., Ruthardt B.B. Methods for downhole soil water sensor calibration Complications of bulk density and water content variations. Vadose Zone J. 2022; 21(6):e20235.
31. Ramesh K., Biswas A.K., Patra A.K. Zeolitic farming. India. J. Agron. 2015; 60(2):185-191.
32. Hosseinalizadeh M., Yeganeh H., Aranian V., Mohammadian Behbahani A., Khermandar K. Effects of Rainwater Harvesting and Soil Amendments on Dryland Rehabilitation (Case Study: North Khorasan, Jajarm). ECOPERSIA 2026;14(2):145-160.
33. Jiang J., Chen A., Qi J. Morphophysiological responses and gene regulation of two bermudagrass cultivars differing in response to drought stress. Chem. Biol. Technol. Agric. 2025; 12(1):54.
34. Whitlark, B. Revised Recommendations for the USGA Method of Putting Green Construction. United States Golf Association (USGA), February 5:2018:1-32.