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Influence of some polymers and microorganisms on the soil physical properties under drought conditions

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Abstract

This study evaluated the effects of two Super Absorbent Polymers (SAPs) types, P1 and P2, and four microbial isolates (*Trichoderma harzianum*, two Actinomycetes sp., and *Bacillus subtilis*) on improving some soil physical properties. The results showed that SAP application, alone or in combination with microbes, significantly reduced bulk density by 6.1% and increased porosity by 5.2% compared to the control. Specifically, the P1C (P1 polymer + Actinomycetes 1) treatment increased water holding capacity by 48.7%, field capacity by 169.4%, permanent wilting point by 180.5%, and available water by 149.8% compared to control based on data from the results. The P1C treatment improved soil properties and moisture characteristics. The synergistic effect of polymers and microbes emerged as an effective strategy to modify soil properties. This study provides valuable insights into using SAP-microbe amendments to enhance soil physical properties, water availability, and agricultural productivity in drought conditions.

Keywords: soil amendments, physical properties, polymers. microorganisms.

INTRODUCTION

Super Absorbent Polymers (SAPs) have become crucial in enhancing agricultural soils' physical properties and water availability. SAPs are hydrophilic polymer networks that absorb and retain significant amounts of water within their structure (Mahgoub., 2020). When applied to soils, these particles swell by absorbing water, altering soil properties and creating a reservoir of plant-accessible water in the root zone (Seddik et al., 2019). The ability of SAPs to absorb and retain water is due to their hydrophilic functional groups (Khodadadi, 2018). Numerous studies have investigated the effects of SAP application on improving the physical health and moisture dynamics of sandy soils with low organic matter content .El-Kady and Borham (2013) showed that adding hydrogel to the soil at high concentrations under 35% Available Soil Moisture Depletion (ASMD) prolongs water retention, increases field capacity and available water, and promotes soil aggregate formation. In turn, decreased soil bulk density. Additionally, Swollen SAP particles occupy pore spaces between soil grains, reducing bulk density

while improving soil structure and aeration levels (Parvathy & Jyothi,2014). However, it should be noted that over-application may lead to adverse impacts on soil properties, such as reduced hydraulic conductivity and altered microbial activity (Yang et al.,2022). Therefore, determining optimal rates for adding SAP based on factors such as soil type or crop growth is essential for maximizing benefits. Thombare et al. (2018) showed that the hydrogel, which could absorb up to 800 ml water per gram after being added to soil, significantly improved its porosity, moisture absorption, and retention capacity. They found that the water holding capacity increased up to 54% of its original capacity, and porosity also increased up to 9% of its original capacity. Moreover, the soil field capacity increased under both SAP treatments compared to the control. Zheng et al. (2023) showed that SAP application increased soil moisture by 6.2–32.8% and decreased soil bulk density by 5.5–9.4% compared to the control group. These findings provided valuable insights into using SAP amendments effectively in coarse-textured arid or semi-arid regions where improvement regarding available water infiltration characteristics and structural stability is required. In addition to directly enhancing soil water retention, SAP amendments can stimulate microbial activity and growth in the rhizosphere (Parvathy & Jyothi,2014). The increased microbial biomass and diversity in SAP-amended soils enhance nutrient cycling and availability (Li et al.,2020). Several studies have revealed that combining SAP application with bio-inoculants containing Plant Growth-Promoting Rhizobacteria (PGPR) and fungi can have synergistic benefits on soil properties and plant performance, compared to their solo application for instance, SAP and PGPR co-application improves soil aggregation and fertility, photosynthetic activity, antioxidant status, and yield in crops grown under drought condition ((Yaseen et al., 2019).). This study evaluates how two different types of SAP and microorganisms improve soil physical properties under drought conditions.

MATERIALS AND METHODS

1 Experimental Site and Soil Characteristics

The experiment was conducted at an agricultural farm of Sohag University in new Sohag City, which is about 15 km south-west of Sohag city and located at the western edge of the Nile valley (26°28' 13" N and 31°40' 20" E). as illustrated in Figure 1. The climate conditions in Table (1) and Figure (2) demonstrate an overall arid, low rainfall pattern across the growing season. The temperature exhibited a seasonal warming trend, with average monthly temperatures ranging from a winter low of 14°C in January to a summer peak of 30°C in May. Wind velocities accelerate in parallel to temperatures, averaging 7 knots in winter months and reaching 9.1 knots by May. Relative humidity declines in summer, falling from winter highs of around 51% down to approximately 19% in spring. Precipitation occurs mostly absent across all months, with 0-0.1mm average monthly accumulation. The Soil properties were assessed using established methods, and the results are summarized in Table 1.

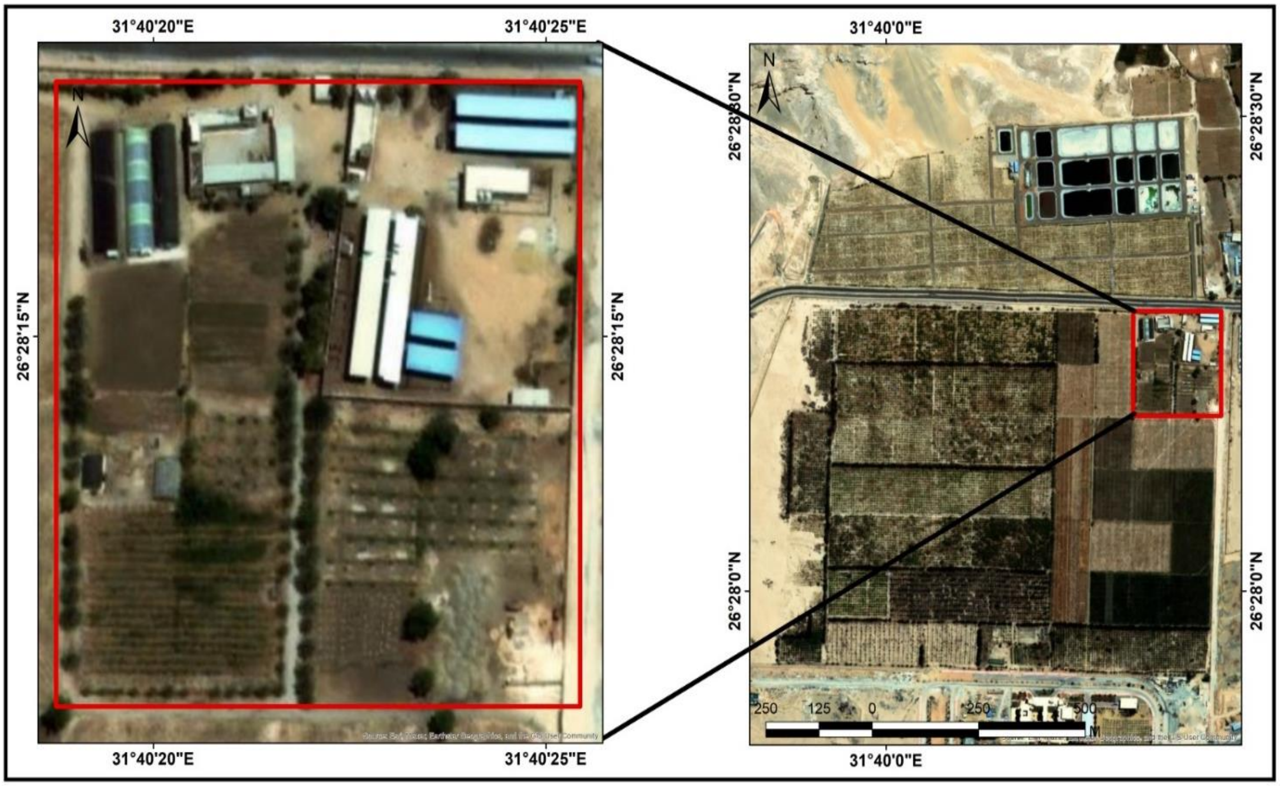


Figure (1) The location map of the study area.

Table (1) The average climatic condition of the study area in 2021-2022 (https://weatherspark.com/).

Average	Dec. 2021	Jan. 2022	Feb. 2022	Mar. 2022	Apr. 2022	May. 2022
Temperature	16	14	16	20	25	30
Wind Speed	7	7	7.4	8	8.4	9.1
Relative humidity	50.38	51.83	46.22	32.75	18.12	19.58
Precipitation	0	0.1	0	0	0	0

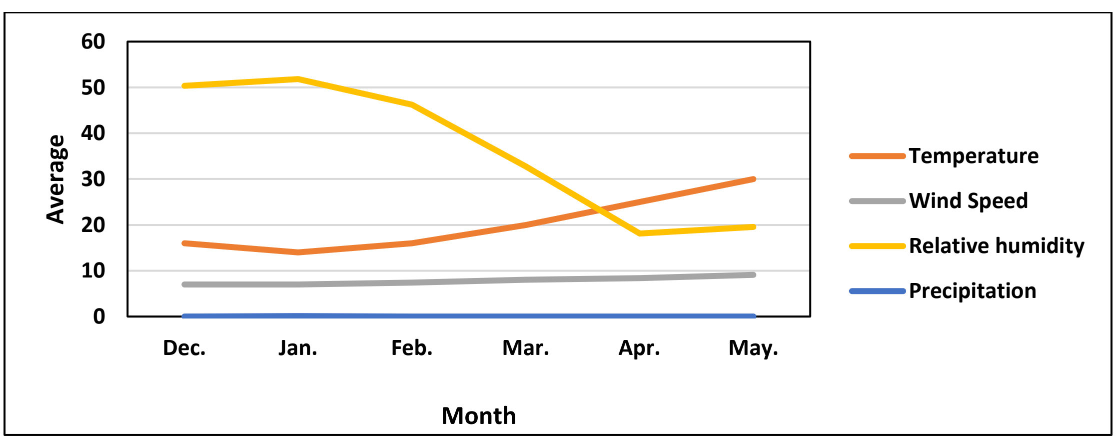


Figure (2): The average climatic condition of the study area in 2021-2022.

Table (2) shows physical and chemical analysis of the experimental soil

Soil property	Used soil	Methods
Soil physical analysis		
Particle size distribution		
Sand %	78.2	
Silt %	7.3	
Clay %	14.5	Piper, (1950)
Texture grade	Sandy loam	
Bulk density Mg m^{-3}	1.49	Richards (1954).
Particle density Mg m^{-3}	2.62	Richards (1954).
Total porosity %	43.13	Richards (1954).
Water holding capacity %	25.3	Black (1965)
Field capacity %	10.2	Black (1965)
Wilting percentage %	4.8	Black (1965)
Available water %	5.4	Klute (1986).
Soil chemical analysis		
Soil pH	8.55	McLean (1982).
EC (dS m^{-1})	0.69	Jackson (1973).
OM (%)	0.43	Walkley and Black (1934)
Available N (mg kg^{-1})	17.8	Subbiah and Asija (1956).
$NaHCO_3$- extractable P (mg kg^{-1})	3.21	Olsen et al., 1954).
NH_4OAc- extractable K (mg kg^{-1})	98.70	Carson, (1980)

Soil Amendments

1- **Hydrogel**

Two types of hydrogel polymers were utilized in this study. The first type, known as "Barbary Plant G3," included 40% hydropolymer, 6.5% nitrogen (N), 4.8% phosphorus (P), and 8.2% potassium (K), with a water-holding capacity ranging from 300% to 500%. It was supplemented with numerous micronutrients, including 200 mg/kg boron, 60 mg kg^{-1} copper, 480 mg kg^{-1} iron, 160 mg kg^{-1} zinc, 600 mg kg^{-1} manganese, and 60 mg kg^{-1}molybdenum. Additionally, the second type (P2) was a combination of anionic hydrogel (polyacrylamide k polycarboxylate gel with 30% anionicity) and cationic hydrogel (polyacrylamide allylamine hydrochloride gel with 20% anionicity). It had a white to slightly yellow grain appearance with grain sizes ranging from 0.25 to 1 mm. The bulk density was 0.6 Mg m^{-3}, which was insoluble in water and organic solvents. A 0.1% solution in distilled water provided a pH of 7.0 ± 0.5. The cation exchange capacity ranged from 2045 to 2175 cmolc kg.$^{-1}$ The hydrogel polymers were obtained from Lucky Star TG., Egypt, and another named "Aqua Gool, AG, Russian production. The studied polymers were thoroughly mixed with soil at a rate of 2g kg^{-1} soil, at a rate of 0.2% of the weight of the pot.

2. Microorganisms

Four microbial isolates, selected as bioagents and biofertilizers, were obtained from the stock cultures of the plant pathology department, faculty of agriculture, Sohag University. These isolates included one strain of the fungus *Trichoderma harzianum Rifai*, two strains of *Actinomycetes sp*., and one strain of the bacterium *Bacillus subtilis Cohn*.

3. Microbial Inoculation

The inocula of *B. subtilis* and *Actionomycetes* sp. were cultured in nutrient glucose agar broth for three days at 150 rpm and 25°C. The bacterial suspensions were adjusted to 5 × 106 CFU/ml using sterile distilled water and a hemocytometer. Similarly, the *T. harzianum* inoculum was cultured in potato dextrose agar broth for 14 days at 150 rpm and 28°C. The fungal growth was blended and adjusted to 5 × 104 CFU/ml. The sterile soil was inoculated with 50 ml of each microbial isolate seven days before wheat planting and irrigated as needed.

Experimental Design and Treatments

A completely randomized design with three replicates was employed for the pot experiment. Plastic pots measuring 35 cm in diameter and 30 cm in depth were utilized. Each pot was filled with 8.5 kg of dried soil. The experiment comprised a total of 16 treatments, representing combinations of two types of hydrogel polymers (P1 and P2) and four different microbial isolates (*Trichoderma sp, Actinomycetes 1 sp, Actinomycetes* 2 sp, and *Bacillus sp*). These treatments are summarized in Table 2.

Table (3) The applied treatments in the experiment.

No	Treatments	
1	Control	Cont.
2	Polymer1	P1
3	Polymer2	P2
4	*Trichoderma harazanium*	A
5	*Streptomyces rochei*	B
6	*Streptomyces atrovirens*	C
7	*Bacillus subtilis*	D
8	*Polymer1+Trichoderma sp*	P1A
9	*Polymer1+ Actynomicetes 1*	P1B
10	*Polymer1+ Actinomycets2*	P1C
11	*Polymer1+ Bacillus*	P1D
12	*Polymer2+Trichoderma sp*	P2A
13	*Polymer2+ Actynomicetes 1*	P2B
14	*Polymer2+ Actinomycets2*	P2C
15	Polymer2+ *Bacillus*	P2D

Planting and drought stress

Wheat seeds (variety: Shandawel one) were sown in each pot, with ten seeds per pot, on November 29, 2021. After 15 days of germination, drought stress was imposed by irrigating the plants at 8-day intervals until the experiment. The total period of cultivation is 160 days until plants are harvested.

Soil Analysis After Cultivation

After plant harvest, soil samples were collected from each pot for physical analysis. The assessed parameters included the water holding capacity, bulk density, particle density porosity permanent wilting point, field capacity, and Available water. The methods used in analyzing these properties are indicated in Table 1

Statistical analysis

The data were analyzed using analysis of variance (ANOVA) in SPSS version 27 software. For comparing the studied treatments, Duncan's multiple range test was performed at a significance level of $p<0.05$ (Gomez and Gomez, 1984). Microsoft Excel was utilized for the graphical representation of the data in charts and figures.

RESULTS AND DISCUSSION

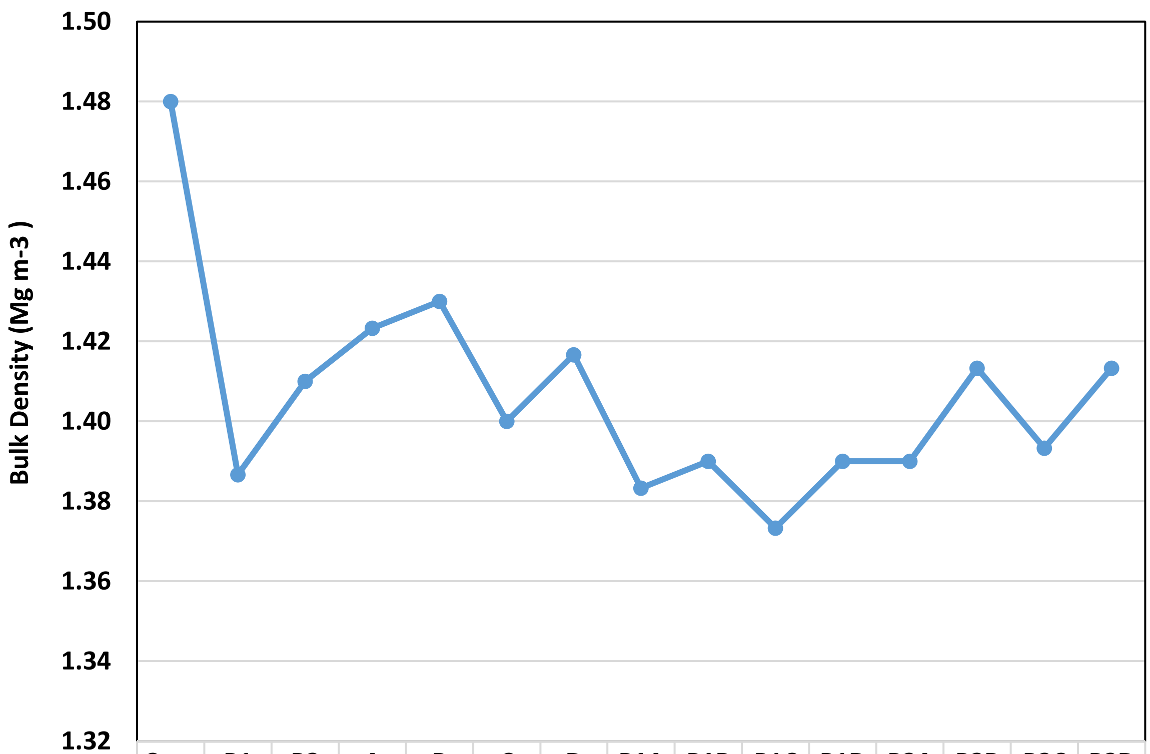
Bulk Density

Data in Figure (3) showed that the application of polymers influences soil bulk density. The lowest value of 1.37±0.01 Mg m^{-3} was observed in the P1C treatment. In contrast, the untreated control exhibited the highest bulk density of 1.48±0.01 Mg

m^{-3}. Notably, the average bulk density decreased significantly from 1.48 ± 0.01 in the control to 1.39±0.02 and 1.41±0.01 Mg m^{-3} with the application of P1 and P2, respectively. This decrease can be attributed to several factors, including the water-absorbent nature of polymers, their volume expansion upon water absorption, and their ability to replace mineral matter with organic copolymer. The addition of microbes to the soil further contributed to a reduction in bulk density, with average values of 1.42±0.01, 1.43±0.01, 1.40±0.03, and 1.41±0.01 Mg m^{-3} observed for treatments A, B, C, and D, respectively, compared to the control (1.48±0.01). This reduction is likely due to the combined effect of water storage facilitated by polymer application and the positive influence of soil microbes on microbial biomass, organic matter content, and soil aggregation. These findings align with the work of Chen et al. (2019) and are consistent with prior studies by Nada and Blumenstein (2015), Al-Omran and Al-Harbi (2020), Hou et al. (2018), and Lozano et al. (2021).

Porosity

The data in Figure (5) indicated that the porosity, inversely related to bulk density, demonstrated significant variations across treatments. The highest porosity of 45.63±0.66% was recorded in the P1A treatment, while the control exhibited the lowest porosity at 34.44±0.34%. The soil porosity significantly increased to 45.29±0.29% with the P1 amendment and 44.14±0.32% with the P2 treatment. Microbe addition also had a substantial impact, raising the average soil porosity to 44.47±0.42, 44.64±0.17, and 44.66±0.51% with A, B, C, and D microbes, respectively. Interestingly, the interaction between polymers and microbes in the P1C treatment yielded the most favorable results, surpassing other treatments and the control. These findings resonate with studies by Shahid et al. (2012), El-Hady et al. (2015), and Patel et al. (2023).



	Cont	P1	P2	A	B	C	D	P1A	P1B	P1C	P1D	P2A	P2B	P2C	P2D
Series1	1.48	1.39	1.41	1.42	1.43	1.40	1.42	1.38	1.39	1.37	1.39	1.39	1.41	1.39	1.41

Fig (3) Effect of applying soil amendments on soil bulk density

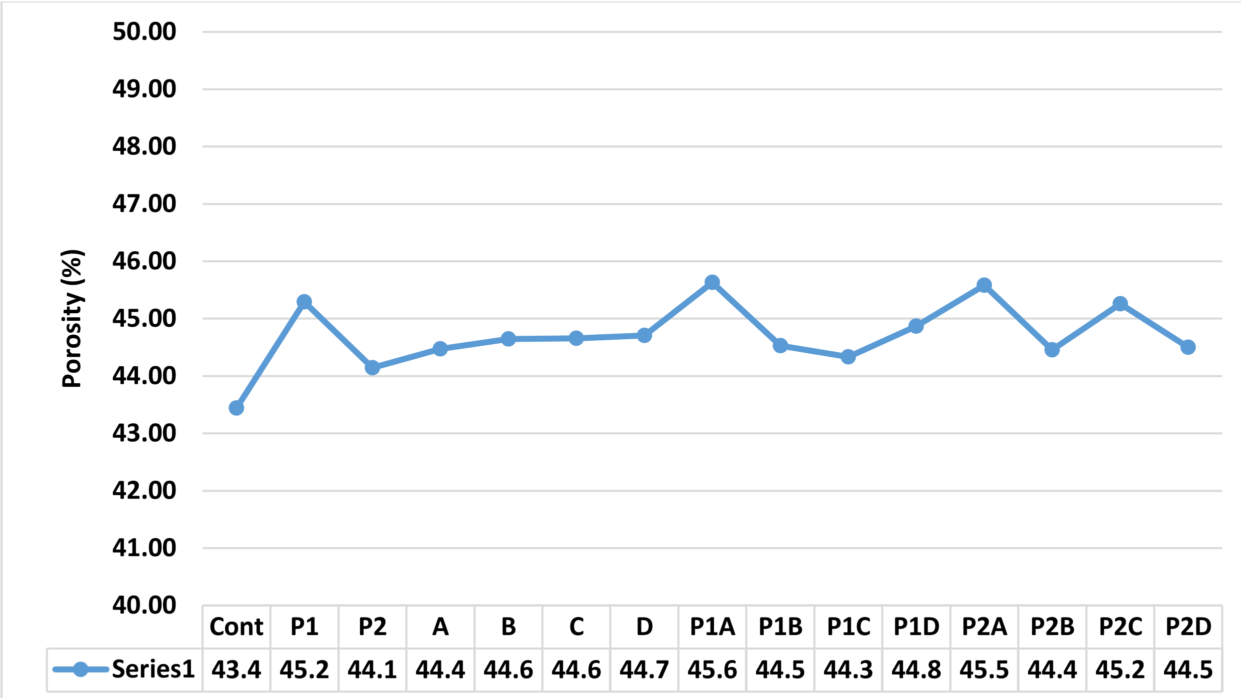


Fig (5) Effect of applying soil amendments on soil porosity.

Water Holding Capacity, Field Capacity, Wilting Point, and Available Water Content in the Soil:

a. Water-Holding Capacity (WHC):

The presence of polymers in the soil had a profound impact on WHC. As presented in Table 4, our findings reveal a significant increase in WHC due to the application of polymers, microbes, and their interactions. The maximum WHC (38.60±0.05%) was observed in the P1C treatment, while the control treatment exhibited the lowest WHC (25.97±0.29%). Specifically, applying P1 and P2 polymers led to a substantial average increase in soil WHC of 34.19±0.60% and 31.8±0.08%, respectively, compared to the non-treated soil (control). Interestingly, soil inoculation with microbes alone resulted in a modest and statistically non-significant improvement in WHC. The interaction between polymers and microbes, notably in the P1C treatment, emerged as the most effective approach in enhancing WHC compared to other treatments. The addition of super absorbent polymers in the soil can improve soil water holding capacity. These results align with the (El-Tohamy et al., 2014; Li et al.,2018; Thombare et al., 2018).

b. Field Capacity (FC.):

Our data, as shown in Table (4), demonstrates a substantial increase in water content at field capacity (FC) due to the application of polymers. The P1C treatment exhibited the highest FC (23.37±0.38%), while the control treatment recorded the lowest FC (8.68±0.29%). Polymers contributed to a notable 1.88-2.10-fold increase in FC Compared to the control, further highlighting their effectiveness in improving water retention capacity. Additionally, soil inoculation with microbes led to significant enhancements in FC, with 1.44-1.71-fold increases observed in the P1 and P2 treatments, respectively, compared to the control. Notably, the combined application of polymers and microbes demonstrated the highest FC values, surpassing other treatments and a similar study. Dahri et al. (2019) found that Superabsorbent Polymers (SAP) in powder and crystal forms decreased soil bulk density, increasing porosity and field capacity. Seddik et al. (2019) showed synthetic soil conditioners improved soil properties, enhancing field capacity and nutrient availability, positively impacting plant growth and yield in sesame and wheat.

c. Permanent Wilting Point (PWP):

The soil water content at the permanent wilting point (PWP) increased significantly due to the interaction between polymer application and microbial inoculation. The P1A treatment recorded the highest PWP (9.13±0.18%), while the control treatment exhibited the lowest PWP (3.13±0.23%). These results translate to 1.51-, 1.49-, 1.73-, and 1.64-fold increases in PWP values for the A, B, C, and D microbe treatments, respectively, compared to the control. These results align with the findings reported by Seddik et al. (2019).

d. Available Water Content (AWC):

A statistically significant difference in available water content (AWC) was observed between treatments containing polymers and the control (Table 4). The highest AWC (14.58%) was recorded in the P1C interaction treatment, while the control exhibited the lowest AWC (5.84±0.81%). Applying P1 and P2 polymers led to significant increases of 1.8 and 1.9-fold in AWC compared to the control.

These findings underscore the potential of polymers to enhance soil water-holding capacity, field capacity, wilting point, and available water content. These results align with the capacity of polymers to absorb water at a rate significantly higher than their weight and emphasize their potential impact on soil water management and irrigation efficiency (Abedi-Koupai and Sohrab, 2004; Yang et al., 2014; Baran et al., 2015; Montesano et al., 2015; Patel et al., 2023).

The role of soil microbes, such as Bacillus bacteria and Actinomycetes, in producing polysaccharides that contribute to soil aggregation and water retention is significant (Ren et al., 2022). Also, Trichoderma, a type of soil fungus, can bond to soil particles by mycelium or act as a binding agent in soil particles by secreting insoluble extracellular substances. This action improves the soil's Porosity and water-holding capacity (Shi et al., 2022).

Wheat growth and productivity:

The study found that the applications of polymers and microbes in wheat cultivation enhanced crop growth and yields. Compared to untreated plants, The P1C treatment as a combination of polymer one and microbe C led to substantial crop yield and growth increases. P1C enhanced tiller number by 125% and 1000 grain weight by 42%, reflecting dramatically higher yield potential. Vegetative growth improved, with 23% shoot length and 57% more leaves per plant under P1C application.

Table 4: Effect of applied soil amendments on soil physical properties (Water holding capacity, Field capacity, Wilting point, and Available water)

Treatments	Water holding capacity	Field capacity	Permanent Wilting point	Available water
	%			
Control	25.97^{g}±0.29	8.68^{i}±0.29	3.13^{g}±0.23	5.84^{i}±0.81
P1	34.19^{d}±0.60	18.24^{cde}±0.32	7.35^{bcd}±0.38	10.89^{de}±0.12
P2	31.82^{e}±0.08	16.28^{f}±0.57	5.53^{ef}±0.68	10.74^{de}±0.65
A	26.58^{fg}±0.17	13.50^{gh}±0.18	4.73^{f}±0.13	8.77^{g}±0.26
B	26.70^{fg}±0.70	13.33^{h}±0.99	4.69^{f}±0.47	8.64^{g}±0.52
C	27.34^{f}±0.09	14.82^{g}±0.55	5.41^{ef}±0.27	9.41^{fg}±0.27
D	26.22^{g}±0.10	12.47^{h}±0.41	5.13^{ef}±0.41	7.33^{h}±0.47
P1A	37.63^{b}±0.57	22.32^{ab}±0.56	9.13^{a}±0.18	13.18^{b}±0.39
P1B	37.51^{b}±0.12	21.06^{b}±0.39	8.51^{abc}±0.20	12.55^{bc}±0.18
P1C	38.60^{a}±0.05	23.37^{a}±0.38	8.78^{ab}±1.05	14.58^{a}±0.77
P1D	33.79^{d}±0.37	19.53^{c}±0.38	7.77^{abcd}±0.19	11.77^{cd}±0.19
P2A	36.29^{c}±0.10	18.63^{cd}±0.47	7.31^{cd}±0.23	11.31^{cde}±0.23
P2B	35.55^{c}±0.21	17.85^{de} ±0.43	6.93^{d}±0.21	11.01^{de}±0.17
P2C	35.80^{c}±0.10	18.70^{cd}±0.42	7.35^{bcd}±0.21	11.35^{cde}±0.21
P2D	35.70^{c}±0.35	16.80^{ef}±0.38	6.43^{de}±0.16	10.37^{ef}±0.22
Significance	0.001	0.001	0.001	0.001

CONCLUSION

This study showed that applying Super Absorbent Polymers (SAPs), either alone or in combination with beneficial microbes, can significantly enhance the physical properties of sandy loam soils. Compared to the untreated control soil, adding SAPs increased porosity, water holding capacity, field capacity, permanent wilting point, and available water content while significantly reducing bulk density. The use of polymers and microbes together exhibited an effective strategy, with the P1C treatment (SAP P1 + Actinomycetes 1) producing the most favorable results in altering soil composition and water availability. The rhizosphere's soil aggregation, nutrient cycling, and microbial activity were all enhanced by the synergistic interactions between the SAPs and microbial inoculants. Overall, this research provides significant previously unknown information about using SAP-microbe soil additives to improve plant water availability and crop production in arid sandy soils. SAP application holds considerable promise to promote food security and effective water use in marginal situations with appropriate rates adapted to specific soil types and crops.

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الملخص العربي

تأثير بعض البوليمرات والكائنات الحية الدقيقة على الخواص الفيزيائية للتربة تحت ظروف الجفاف

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تهدف هذه الدراسة إلى تقييم تأثير نوعين من البوليمر SAP فائق الامتصاص(P1 و P2) وأربع عزلات ميكروبية على بعض الخواص الفيزيائية للتربة الطمية الرملية تحت ظروف الجفاف. أظهرت النتائج أن تطبيق البوليمر فائق الامتصاص ، سواء بمفرده أو بالاشتراك مع الميكروبات، قلل بشكل كبيرمن الكثافة الظاهرية بنسبة 6.1% وزيادة المسامية الكلية بنسبة 5.2% مقارنة بالكنترول . على وجه التحديد، أدت معالجة P1Cإلى زيادة القدرة القصوي للتربة على الاحتفاظ بالمياه بنسبة 48.7%، والسعة الحقلية بنسبة 169.4%، ونقطة الذبول الدائم بنسبة 180.5%، والماء الميسر بنسبة 149.8% مقارنة بالكنترول وبناء علي النتائج السابقة . أعطت المعاملة P1C أفضل النتائج فيما يتعلق بتحسين خصائص التربة وخصائص الرطوبة. ظهر التأثير التآزري للبوليمرات والميكروبات كإستراتيجية فعالة لتعديل خصائص التربة. توفر هذه الدراسة رؤى قيمة حول استخدام تعديلات البوليمرات والميكروبات لتعزيز توافر المياه والإنتاجية الزراعية في التربة الجافة .