Soil Environ. 44(2): 145-155, 2025
DOI: doi.org/10.25252/SE/2025/253718
Online ISSN: 2075-1141
Print ISSN: 2074-9546

Effects of hydrogel application on soil water retention characteristics, soil evaporation, and saturated hydraulic conductivity in soils with different textures

***Nevzat Aslan**[*1] and Mustafa Yıldırım Canbolat*[2]
[1]Department of Soil Science and Plant Nutrition, Faculty of Agriculture, Siirt University, Siirt, Turkiye
[2]Department of Soil Science and Plant Nutrition, Faculty of Agriculture, Atatürk University, Erzurum, Turkiye
[Received:** January 20, 2025 **Accepted:** November 24, 2025 **Published Online:** November 30, 2025**]

Abstract

Hydrogels allow water to be retained in soil environment and released slowly. This study investigated the effects of hydrogel applied at different levels (0, 0.05, 0.1, 0.3, 0.5, and 0.7 (w/w)) to soils with clay, loamy, and sandy loam textures on soil water relations. The changes in bulk density, field capacity, permanent wilting point, available water content, evaporation process (drying curve), and hydraulic conductivity due to hydrogel application were determined. With the increasing rate of hydrogel, soil bulk density decreased by 6.9%, 7.1%, and 12.5% in clay, loam, and sandy loam textured soils respectively. Similarly field capacity and available water content increased vin all soils with application. The average water contents of hydrogel-added clay, loam, and sandy loam textured soils compared to the control soil during the evaporation process from saturated to dry state were found to be 29.5%, 38.11%, and 88.47%, respectively. Increasing the dose of hydrogel applied to the soil, increased the hydraulic conductivity which are lower in loamy textured soils than in clay and sandy loam textured soils.

Keywords: Soil texture, hydrogel, soil bulk density, soil water characteristics, hydraulic conductivity

Introduction

Problems caused by spatial and temporal changes in soil and water resources as a result of climate change may arise from the combined interactions of natural and anthropogenic activities. Given the pressures associated with rapid population growth, increasing water scarcity, and changing environmental conditions, ongoing research has increasingly focused on developing alternative irrigation strategies. These efforts aim to increase water use efficiency in agricultural systems. Problems such as deterioration in soil quality, drought, water scarcity, and lack of water security are watched with concern worldwide and different solutions are being worked on. The effects of climate change on soil properties and water use have been investigated by many researchers in different climatic conditions. It is emphasized that sustainable soil management practices, which are the focus of these studies, will provide positive results in terms of both soil quality and effective use of water.

In crop production, the application of techniques that preserve soil moisture and increase the water-holding capacity of the soil plays an important role in ensuring the effective use of limited water resources and supporting long-term agricultural sustainability.

Irrigation water, which is a limited resource, should be used effectively (Pereira *et al.*, 2002). Excessive irrigation causes the formation of barren soils in impermeable soils (Amer, 2021), and the infertility of soils by washing the nutrients in well-drained soils (Song *et al.*, 2022). Excessive irrigation sometimes prevents the sustainability of the soil by creating insoluble problems and sometimes increases production costs (Ziolkowska, 2015).

It was reported by FAO that the cultivated agricultural area in the world is 1.560 million hectares, of which 1.221 million hectares (78%) is dry farming and 60% of agricultural production is provided from these areas, and irrigated agricultural lands, which were 139 million hectares in 1961, increased to over 349 million hectares in 2020 (FAO, 2022). During this period, irrigated agricultural lands worldwide have almost doubled in the last 60 years. As water scarcity continues to be a problem in the world, soil and plant management practices have been developed to increase crop production with less water (Busari *et al.*,

***Email:** nevzat.aslan@siirt.edu.tr
Cite This Paper: Aslan, N. and M.Y. Canbolat. 2025. Effects of hydrogel application on soil water retention characteristics, soil evaporation, and saturated hydraulic conductivity in soils with different textures. *Soil Environ*. 44(2): 145-155.

2015; Wang *et al.*, 2018). It has been tried to increase the water-holding capacity of the soil by adding organic and inorganic materials with high water-holding capacity to the soil by arranging the structure of the soil. Researchers have investigated different solutions regarding effective water use. In addition to preventing water stress in crop production, where water consumption is highest, applying soil conditioners to the soil to improve the physical properties of the soil is greatly beneficial. One of the materials that serve this purpose is hydrogel applications to the soil. Hydrogels are hydrophilic and polymeric materials with the ability to absorb and release large amounts of water (Peppas, 2000). Hydrophilic polymers such as hydrogels are increasingly utilized as soil amendments to optimize water-use efficiency under water-limited conditions. These hydrogels can take up and retain extremely large quantities of water, typically 200–400 times their dry weight (Kalhapure *et al.* 2016).

Mikkelsen (1994) grouped hydrogels as synthetic, semi-synthetic, and natural polymers. Synthetic polymers are structurally cross-linked and do not dissolve in solutions. Synthetic polymers in the form of crystals or small beads are hydrophilic and are collectively known as hydrogels, (Akhter *et al.*, 2004; Abedi-Koupai *et al.*, 2008) or superabsorbent polyacrylamide (Ashraf *et al.*, 2021). Hydrogels turn into gels when in contact with water and can absorb hundreds of times their weight in water (Fanta *et al.*, 1978; Ahmed, 2015; Suresh *et al.*, 2018).

Agricultural hydrogels directly or indirectly affect soil properties and the development of soil conditions. These effects include increasing the water retention capacity of the soil, increasing hydraulic conductivity by affecting pore geometry, increasing water use efficiency, prolonging the time to reach the permanent wilting point, drought stress reduction, improving drainage, and better water management (Neethu *et al.* 2018; Nirmala and Guvvali, 2019).

In agriculture, hydrogels are applied as practical and cost-effective amendments to improve water-use efficiency and sustain higher crop productivity under water-limited conditions.

Agriculture benefits greatly from the addition of soil amendments such as hydrogels, which improve the hydraulic properties of the soil and help prevent water stress (Amine *et al.*, 2014). Superabsorbent polymers (SAPs) are widely used as absorbents for water especially in arid and semiarid regions since they significantly improve water usage efficiency and soil water storage ability (Liao *et al.*, 2016; Chang *et al.*, 2021).

The potential use of hydrogels or superabsorbent polymers (SAP) as soil amendment agents to improve agricultural production and reduce water losses under water stress conditions has been investigated (Seybold, 1994; Saha *et al.*, 2020; Malik *et al.*, 2022; Takahashi *et al.*, 2023). The ability of hydrogels to absorb and retain large amounts of water has demonstrated their effectiveness as a solution to alleviate the impact of drought and water scarcity on plant growth (Nirmala and Guvvali, 2019; Skrzypczak *et al.*, 2020; Patra *et al.*, 2022).

The research findings emphasize the significant potential of using hydrogels as soil amendments in developing sustainable water management strategies in agriculture, enhancing agricultural production, and increasing resilience against water scarcity (Ashraf *et al.*, 2021; Patra *et al.*, 2022; Wu *et al.*, 2023).

This product is a hydrophilic material needed for crop production where drought causes significant damage and water is expensive or lacking. Gel-structured synthetic polymers contribute significantly to plant growth in arid regions by helping water retention in sandy soils (Chartzoulakis and Bertaki, 2015).

The use of superabsorbent hydrogels has the potential to improve both the water-holding capacity and the hydro-physical behavior of sandy soils. According to studies, the hydrogel application improves moisture retention in sandy soils and limits water loss through deep percolation (Narjary *et al.* 2012; Abdallah 2019a;)

Cross-linked polyacrylamides (Hydrogels) increase the water-root contact with their flexible gel structure, creating a reservoir in the growth medium for the plant to take in suitable moisture (Johnson, 1984). It has been observed that hydrogels increase the soil water retention rate as well as improve some properties of the soil (Riad *et al.*, 2018; Guo *et al.*, 2020).

Rigas *et al.* (1999) investigated the effects of applying hydrogel to soil to delay wilting points and increase vegetative production during the plant development period. In their research, a positive relationship was found between the germination time, development time, plant height, irrigation interval, above-ground component mass and soil properties, field capacity, wilting point, the amount of available water, and the amount of hydrogel applied in sunflower grown for ten weeks in sandy soil with hydrogel added.

Hydrogel applications to soils with inadequate physical properties increase the effective amount of water that plants

Table 1: Some physical and chemical characteristics of the soils studied

Soil	Clay (%)	Silt (%)	Sand (%)	OM (%)	pH (1:2,5)	$CaCO_3$ (%)	EC (dS m^{-1})	CEC (cmol kg^{-1})	FC (%)	PWP (%)
Clay	51	28	21	2,3	8,4	0.57	0.9	41	63.9	19.1
Loam	26	32	42	1,8	7,3	0.88	1.3	32	48.8	12.7
Sandy Loam	12	15	73	1,5	6,9	0.45	1.1	17	34.3	6.6

OM: Organic matter, EC: Electrical conductivity, CEC: Cation Exchange Capacity, FC: Field Capacity, PWP: Permanent Wilting Point

can use during long drought periods, reduce irrigation frequency, increase the survival time of plants, and, as a result, increase productivity (Jain *et al.*, 2017; Kargar *et al.*, 2017; Nazarli *et al.*, 2010). Hydrogel can increase soil moisture content in coarse-textured soils compared to fine-textured soils. (Abedi-Koupai *et al.*, 2008; Albalasmeh *et al.*, 2022).

This study was conducted to investigate the effects of different levels of hydrogel application on clay, loam, and sandy loam soils on soil water retention characteristics, evaporation, and saturated hydraulic conductivity.

Materials and Methods

Soil

In this study, three soils with different textures sandy loam, loam, and clay, were used. The soil samples were taken from a depth of 20 cm within the plowing layer of agricultural land in the Erzurum plain (39° 55′ N, 41° 61′ E), located in the northeastern part of Turkiye.

According to the long-term averages from the Erzurum Meteorology Station, the average annual precipitation of the region is 430 mm, and 38% of the precipitation is received in spring, 9% in summer, 26% in autumn, and 17% in winter. The average annual temperature is 5.75°C, the average relative humidity is 63.8% and the average evaporation is 1083.9 mm.

The soil samples were air dried, crushed, and sieved through a 2-mm sieve. The physical and chemical properties of the soil samples were determined using the standard procedures. Soil texture was determined by the Day hydrometer method (Gee and Bauder, 1986). The hydraulic conductivity in the saturated state was determined by the constant water level permeameter method (Klute and Dirksen, 1986). The electrical conductivity of the soil saturation extract was measured with an electrical conductivity bridge device (Richards, 1954). The organic matter content was determined by the Smith-Weldon method (Nelson and Sommers, 1982). The lime content of the soils was determined by the Scheibler calcimeter method (Nelson, 1982). The pH of the soils was determined potentiometrically in a 1:2.5 soil-water suspension with a glass electrode pH meter (Mc Lean, 1983). Cation exchange capacity (CEC) was determined by reading the sodium extractable with ammonium acetate in the atomic absorption spectrophotometer after the soil sample was saturated with sodium (Rhoades, 1982). The physical and chemical characteristics of the soils are shown in Table 1.

Hydrogels

Cross-linked polyacrylamide (Hydrogel), which has hydrophilic gel properties, was used in the study. Insoluble hydrophilic polymers in the form of granules can retain water several times their weight after hydration. The preferred hydrophilic polymer in the study is cross-linked polyacrylamide, acrylic acid, potassium salt/ammonium salt, the trade name is Stockosorb Agro. When mixed with water, it forms a gel-like substance with a pH of 8.3 (20ºC). It is non-toxic to plants, soil organisms, and groundwater according to OECD testing.

Bulk density determinations

Bulk density was determined following the cylinder method of Blak and Hartge (1986). Steel cylinders (5 cm height × 5 cm diameter) lined at the base with coarse filter paper were packed with soils treated with six hydrogel levels (0%, 0.05%, 0.1%, 0.3%, 0.5%, and 0.7% w/w) and leveled to the rim. A collar was affixed to each cylinder, and samples were saturated by capillary rise for 24 h. The height of the capillary-saturated samples was measured. Samples were subsequently oven-dried at 105 °C overnight. Bulk density was computed as the oven-dry mass divided by the soil column volume.

Field capacity and permanent wilting point determinations

The samples treated with six levels of hydrogel (0%, 0.05%, 0.1%, 0.3%, 0.5%, and 0.7% (w/w)) were placed in cylindrical pots with an inner diameter of 7 cm and a height of 12 cm, in three replicates. After the pots were placed in a water tank, the pot contents were saturated with capillarity in water for 24 hours. Saturated samples were taken from the water tank, and after the excess water was drained under free drainage conditions, the pot contents were weighed, and the water content of the samples was found on a weight basis, using the dry weight of the pot content. This water content was evaluated as the field capacity parameter of the soils (Twarakavi *et al.*, 2009; Reynolds, 2018).

In the experiment, the permanent wilting point of the soil-hydrogel mixture samples was determined by the direct method of growing sunflower plants. To determine the permanent wilting point of the sunflower (*Helianthus annuus L.*) plant, six levels of hydrogel [0% (control); The samples to which (0%, 0.05%, 0.1%, 0.3%, 0.5% and 0.7% (w/w)) were added were placed in cylindrical pots with an inner diameter of 7 cm and a height of 12 cm, in three replicates. Two sunflower seeds were planted in each pot as an indicator plant at a depth of 0.02 m. Sunflower (*Helianthus annuus L.*) seeds were germinated and the plant was allowed to grow by watering when necessary until three pairs of leaves were formed. After three pairs of leaves were formed, water application to the soil was terminated and the soil surface was completely covered with paraffin wax to prevent the water in the environment from evaporating. After the leaves wilted due to lack of water, the pot was placed in a dark environment overnight. Following this duration, a soil sample was extracted from the pot containing the plants unable to recover their turgor state, and the water content was assessed using the gravimetric method. This water content was considered the permanent wilting point (Cassel and Nielsen, 1986).

Evaporation process and drying curves

Steel cylinders with an internal volume of 100 cm^3 (height 5 cm, internal diameter cm) were used in the evaporation process. In order to determine the moisture content as a function of time during the evaporation process, the samples treated with six levels of hydrogel (0, 0.05, 0.1, 0.3, 0.5%, and 0.7% (w/w)) were placed in cylindrical pots with an inner diameter of 5x5 cm in triplicate. After the cylindrical containers were placed in a water tank, they were saturated with water by capillarity for 24 hours. Saturated samples taken from the water tank were weighed and placed in a controlled environment at a constant temperature of 30°C to monitor the evaporation process. The samples were weighed every other day and dried until approximately the air-dry state was reached. At the end of the evaporation process, time-water content curves (drying curves) were prepared using water content values gravimetrically calculated from the weight of the samples over time (Canbolat *et al.*, 1997).

Saturated hydraulic conductivity measurements

The hydrogel treated samples were placed in cylinders with an inner diameter of 7 cm and a height of 9 cm in three repetitions and they were saturated with capillarity. After saturation by capillarity, the core was transferred to the test device. The saturated hydraulic conductivity was determined using a constant-head device (a Marriot bottle) (Klute and Dirksen 1986)

Statistical analyses

Analysis of variance and Duncan test were used to evaluate the data related to the soil and plant characteristics examined, and correlation and regression analyses were used to determine the relationships between the characteristics (Dowdy and Weardin, 1983).

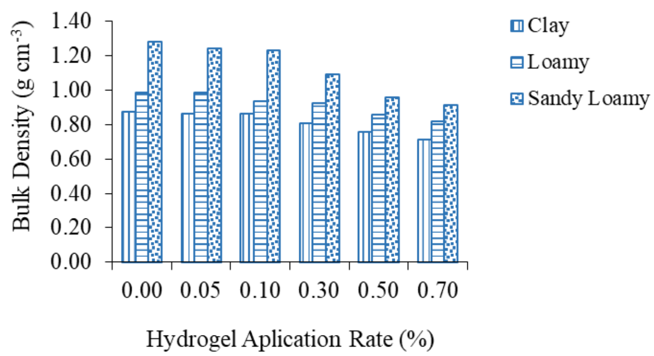


Figure 1: Effect of hydrogel application rate on soil bulk density

Results and Discussion

Effect of hydrogel application on soil bulk density

The effect of hydrogel application on soil bulk density was found to be different between soils and hydrogel application levels (Figure 1). When assessing the disparity in hydrogel application levels concerning soil bulk density values, it was observed that there were no significant differences between the control level and the 0.05% level, as well as between the 0.05% level and the 0.1% level. However, significant distinctions were noted among the remaining application levels. The hydrogel applied at increasing levels to the soil has exhibited a decreasing effect on the soil bulk density. The decrease in bulk density values compared to the control samples, depending on the levels of hydrogel application to the soil, were as follows: in clay soil samples, 1.16%, 1.16%, 8.75%, 13.15%, and 22.53% respectively, in loam soil samples,1.02%, 4.24%, 6.52%, 15.11%, and 17%, respectively, and in sandy loam soil samples, 3.22%, 4.06%, 17.43%, 33.33%, and 36%, respectively. In the study by Errahali *et al.* (2025), applying hydrogel at 0.1%, 0.3%, and 0.5% resulted in bulk density reductions of 56.98%, 35.18%, and 13.17% in clay loam (CL), and 54.54%, 37.37%, and 19.29% in sandy loam (SL).

Soil bulk density is necessary to evaluate many physical soil properties such as porosity, water retention, heat capacity, and soil compaction (Ruehlmann and Körschens, 2009; Abu-Hamdeh, 2003). In this study, the highest hydrogel dose (0.7%) applied to soils reduced the soil bulk density by 22% in clay soils, 17% in loam soils, and 36% in sandy soils. These values are very important for the productivity of the soil. Abdallah (2019b) also stated that hydrogel application to soil can reduce soil bulk density by 5-10%. Bulk density and porosity of the soil are improved with the application of hydrogel (Narjary *et al.*, 2013).

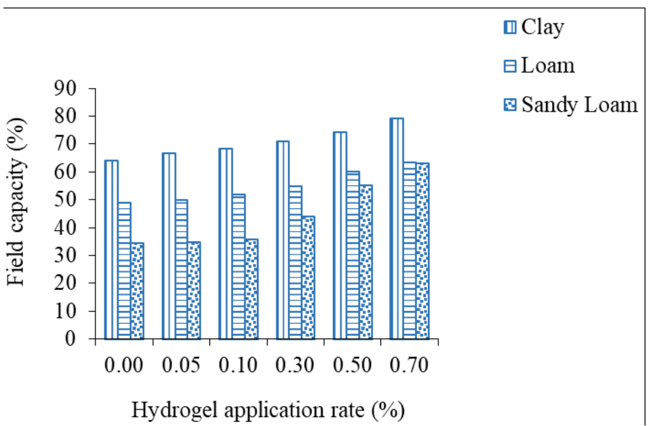


Figure 2: Effect of hydrogel application rate on field capacity

Effect of hydrogel application in soil on the field capacity

According to the results of variance analysis, the presence of hydrogel in clay, loam, and sandy loam textured soils significantly ($p<0.01$) altered the water retention capacity of the soil. As a result of multiple comparison tests, the contribution of hydrogel to field capacity revealed different effects in clay, loam, and sandy loam textured soils. There was no statistically significant difference in field capacity values between control and level 1. However, it has been determined that the effects of other levels on field capacity are different ($p< 0,05$).

Depending on the hydrogel application levels to the soil, field capacity values of samples were compared to control samples as follows, 4.4%, 6.9%, 11.3%, 16.3%, and 24.1%, respectively, in clay soil, 1.8%, 5.9%, 12.1%, 23.2%, and 29.9%, respectively, in loam soil, and 1.5%, 3.8%, 28.9%, 60.9%, and 84.3%, respectively, in sandy loam soil.

Hydrogel addition was more effective in increasing water content in coarse-textured soil than in fine-textured soil. Depending on the application level, the water increase in the first two levels was higher in clay-textured soil than sandy loam soil, while this proportional increase from the third level was more effective in sandy loam-textured soil compared to clay and loam-textured soils (Figure 2). This efficiency can be expressed as an increase in volume of the hydrogel with water absorption, due to the lower resistance to swelling in its environment. Abedi-Koupai *et al.* (2008) have found that the volumetric water content at field capacity is increased by 1.9–4 fold that of the control by adding 8 g kg^{-1} hydrogel. It has been obtained from research that the water content of the soil increases depending on the hydrogel application levels to the soil (Johnson, 1984; Akhter *et al.*, 2004; Shahid *et al.*, 2012; Montesano, 2015).

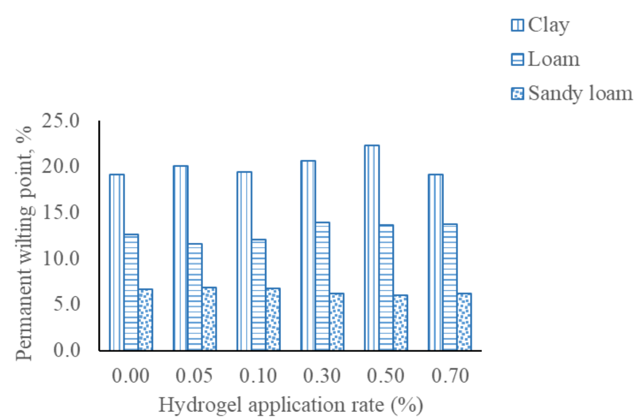
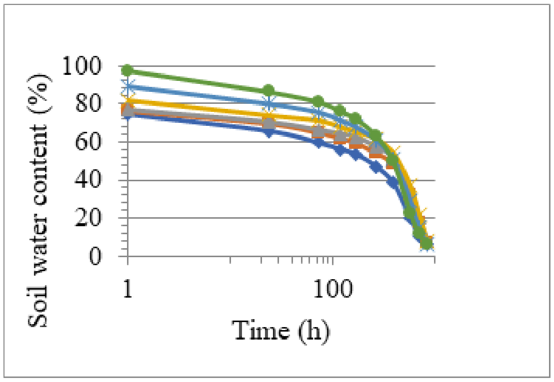


Figure 3: Effect of hydrogel application on soil permanent wilting point

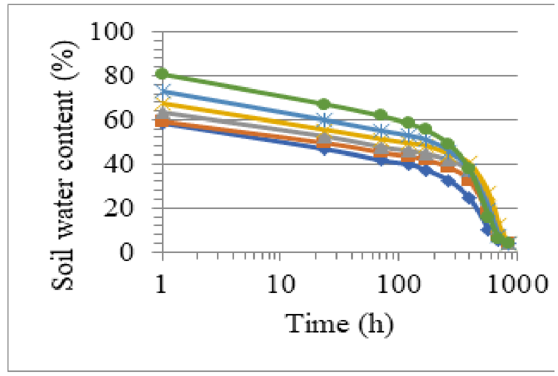
Effect of hydrogel application to soil on permanent wilting point

The contribution of hydrogel to the soil's permanent wilting point is significant among soils; however, no significant differences were found among the application levels of hydrogel.

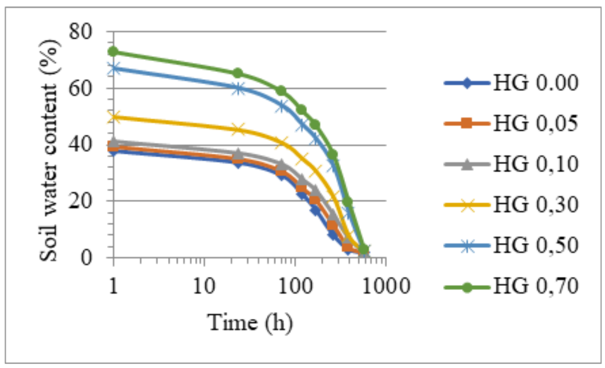
However, it can be evaluated that the difference between the soils is not an effect of the application result of the hydrogel, but is due to the properties of the soils (Figure



(a)



(b)



(c)

Figure 5: Effect on soil water content during the evaporation period of hydrogel (HG) application to (a) clay textured soil, (b) loam textured soil, and (c) sandy loam textured soil

3). According to this result, the duration of soil wetness increased depending on the hydrogel levels added to the soil, and the time required to reach the permanent wilting point of the soil was extended, thus increasing the water use efficiency in the soil.

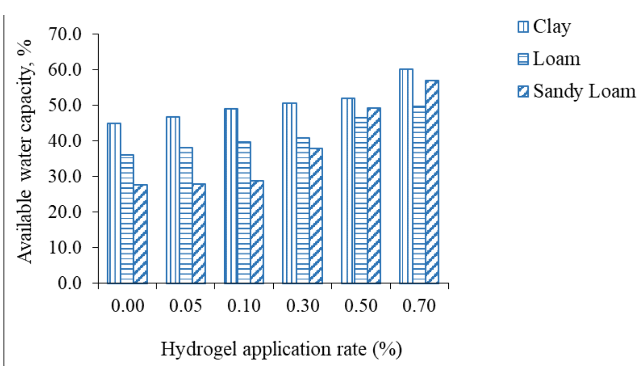


Figure 4: Effect of hydrogel application on soil available water capacity

Effect of hydrogel application on soil available water capacity

Hydrogel applied to the soil at increasing levels was 4.0%, 9.0%, 12.6%, 16.1%, and 34.1% in clay textured soil, respectively, in the available water capacity values compared to the control; 5.7%, 9.7%, 12.9%, 28.6%, and 37.5% in loam textured soil, respectively; in sandy loam textured soil, it caused an increase of 0.9%, 4.3%, 36.9%, 77.8% and 106.1%, respectively. The useful water capacity provided by hydrogel at a concentration of 0.7% in clay and loam textured soils was achieved at a lower concentration of 0.3% in sandy loam textured soils (Figure 4). Abedi-Koupai *et al.* (2008) applied four levels of hydrogel to sandy loam, loam, and clay soils, 2, 4, 6, and 8 g kg^{-1}, and examined the water retention characteristics. Soil water content was found to be 1.8 times greater in clay soil than in control and 2.2 to 3.2 times in loam and sandy loam soil, respectively, with an 8 g kg^{-1} hydrogel application.

Similar to the results recorded in the study of Al Balasmeh *et al.* (2022), it was stated that the hydrogel applied in this study was more effective in coarse-textured soils than in fine-textured soils.

Evaluation of water evaporation from hydrogel-added samples through drying curves

The effect of hydrogel addition applied at different levels to soil samples with clay, loam, and sandy loam textures on soil water content is given in Figure 5. (a), (b), and (c). In all three soil samples, the lowest water content values were measured in the control samples, and the water content values increased due to the increase in the hydrogel content in the samples. Water loss from the samples as a function of time during the evaporation process decreased with increasing hydrogel application level. It was determined that the moisture content values measured at 680 and 580 hours in clay and loamy-textured soils containing 0.3% hydrogel and at 350 hours in sandy loam soil containing 0.7% hydrogel were higher compared to the control soil 109.45%, 140.29%, and 534.12% respectively. Samples exhibiting higher relative moisture levels compared to the control soil during the specified intervals experienced a swift reduction in moisture following those timeframes. During the evaporation process, the air dry threshold value was reached after 840 hours for clay and loam textured soils and 575 hours for sandy loam textured soils. In clay textured soil, 75%, 98.6%, 109.5%, and 46.6% respectively more water content was determined at 680 th hours at 0.05%, 0.1%, 0.3%, and 0.5% hydrogel levels, compared to the control sample. However, at the 120th hour, 0.7% hydrogel level contained 36.1% more water than the control level (Figure 5., a). In the loam textured soil, 71.7%, 129.5%, 157.6%, and 88.7% respectively more water was found at 0.05%, 0.1%, 0.3%, and 0.5% hydrogel levels at the 575th hour compared to the control sample. But, at the 392nd hour, the 0.7% hydrogel level contained 53.2% more water than the control level (Figure 5.,b). For sandy loam soil, the highest water content values occurred between the 264th and 392nd hours of the evaporation process compared to the control. Compared to the control level at 0.05% and 0.3% levels of hydrogel, at the 264th hour, 45% and 169.2%, respectively; at 0.1%, 0.5%, and 0.7% hydrogel levels, 129.8%, 307.5%, and 355.5% more water was detected at the 392nd hour, respectively, compared to the control level (Figure 5., c).

Make longer the time taken for water to evaporate after applying the hydrogel increased the water retention ability of the soil. It can be stated that the application of hydrogel to the soil will provide water to the plant, reduce irrigation time, increase resistance to drought, and enable plant development under stress conditions that occur in arid and semi-arid regions (Akhter *et al.*, 2004; Mandal *et al.*, 2015; Guo *et al.*, 2020). In the study where the effect of hydrogel on evapotranspiration and drought resistance in soils of different textures was investigated, it was emphasized that hydrogel increased the drought resistance period of plants and had a reducing effect on evapotranspiration (Agaba *et al.*, 2010).

Effect of hydrogel application on soil hydraulic conductivity

Figure 5 indicates the effect of hydrogel on soil-saturated hydraulic conductivity. In hydrogel application to the soil, clay, and loam textured soils were found to be no different from each other in terms of hydraulic conductivity values, but sandy loam textured soil was found to be different from the other two soils.

In the evaluation made between hydrogel application levels in terms of hydraulic conductivity values, it was noted that the control application was no different from 0.05% and 0.1% hydrogel levels. However, other hydrogel application levels (0.3%, 0.5%, and 0.7%) were found to be different from each other in terms of hydraulic conductivity values.

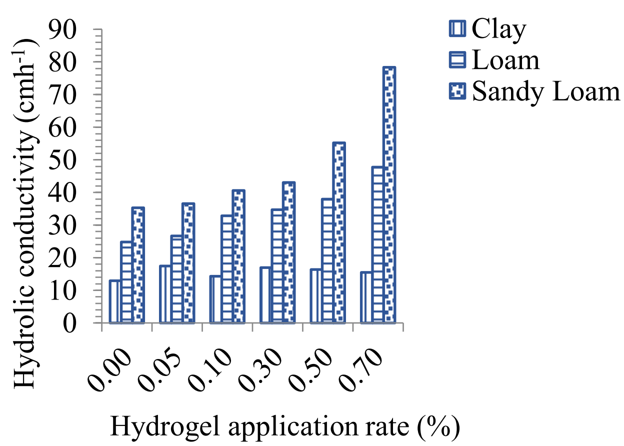


Figure 6: Variation of hydraulic conductivity according to hydrogel application ratio in three different soils

The application of hydrogel to the soil at increasing levels resulted in a consistent increase in the hydraulic conductivity values across different soil textures. The increases were compared according to the control soil. In clay textured soil the increases were 34.8%, 10.4%, 31.1%, 25.9%, and 19.8%. In loam textured soil the increases were 7.4%, 32.3%, 39.7%, 52.6%, and 92.1%. Similarly, in sandy loam textured soil the increases were 3.4%, 14.9%, 21.7%, 56.2%, and 121.7% compared to the control soil.

Han *et al.* (2013), it was noted that when the synthetic hydrogel was applied to the soil, the initial saturated hydraulic conduct decreased, but the saturated hydraulic conduct gradually increased over time. It was emphasized that initially, the swelling of the hydrogels caused the clogging of the soil pores, and then the release of the water stored in the environment increased the hydraulic conductivity. Studies have emphasized that hydrogel has to decrease, increase, and first decrease and then increase effects on saturated hydraulic conductivity (Adjuik *et al.*, 2022).

Conclusion

The use of hydrogels in plant production in arid and semi-arid regions where water scarcity occurs has an important role in water management. A key functional property of polymer hydrogels lies in their ability to absorb and store water at levels several-fold higher than their mass, thereby providing a slow and continuous release of moisture for plant uptake. With the increase in the amount of hydrogel added to the soil, there was a decrease in volume weight and a significant increase in field capacity values, while there was no significant change in the permanent wilting point. Increasing the hydrogel content per unit volume of soil resulted in a measurable decline in bulk density. This response is primarily associated with the substantial volumetric expansion of hydrogel upon hydration, which induces a reorganization of soil particles and increases the overall pore space. The results further demonstrate that this mechanism is more effective in coarse-textured soils, where the closer packing of particles allows for greater structural displacement, whereas its influence is comparatively limited in fine-textured soils. The evaporation time of water from the soil has been extended. Hydrogel added to the soil was particularly effective in increasing hydraulic conductivity in fine-textured soils due to its ability to influence soil pore continuity. In the study, it was noted that the hydrogel was more effective in sandy loam-textured soils than in clay and loam-textured soils. Accordingly, it has been noted that the effectiveness of the hydrogel increases as the soil texture becomes coarser, allowing water to be retained in the soil for a longer time. In general, this study noted that hydrogels will be important in reducing the number of irrigations, ensuring the effectiveness of rain and irrigation water, and preventing drought stress in plants.

Acknowledgment

This article was produced from PhD thesis of the corresponding author.

References

Abdallah, A.M. 2019a. The effect of hydrogel particle size on water retention properties and availability under water stress. *International Soil and Water Conservation Research* 7: 275–285.

Abdallah, A. 2019b. Influence of hydrogel type and concentration, and water application rate on some hydraulic properties of a sandy soil. *Alexandria Science Exchange Journal* 40:347-360.

Abedi-Koupai, J., F. Sohrab, and G. Swarbrick. 2008. Evaluation of hydrogel application on soil water retention characteristics. *Journal of Plant Nutrition* 31(2): 317-331.

Abu-Hamdeh, N.H. 2003. Compaction and subsoiling effects on corn growth and soil bulk density. *Soil Science Society of America Journal* 67(4):1213-1219.

Adjuik, T.A., S.E. Nokes, M.D. Montross, and O. Wendroth. 2022. The impacts of bio-based and synthetic hydrogels on soil hydraulic properties: A review. *Polymers* 14(21):4721.

Agaba, H., L.J. Baguma Orikiriza, J.F. Osoto Esegu, J. Obua, and J.D. Kabasa. 2010. Effects of hydrogel amendment to different soils on plant available water and survival of trees under drought conditions. *Clean–Soil, Air, Water* 38(4):328-335.

Ahmed, E.M. 2015. Hydrogel: Preparation, characterization, and applications: A review. *Journal of Advanced Research* 6(2): 105-121.

Akhter, J., K. Mahmood, K.A. Malik, A. Mardan, M. Ahmad, and M.M. Iqbal. 2004. Effects of hydrogel amendment on water storage of sandy loam and loam soils and seedling growth of barley, wheat, and chickpea. *Plant Soil and Environment* 50(10): 463-469.

Al balasmeh, A.A., O. Mohawesh, M.A. Gharaibeh, A.G. Alghamdi, and M.A. Alajlouni. 2022. Effect of hydrogel on corn growth, water use efficiency, and soil properties in a semi-arid region. *Journal of the Saudi Society of Agricultural Sciences* 21(8):518-524.

Amer, R. 2021. Spatial relationship between irrigation water salinity, waterlogging, and cropland degradation in the arid and semi-arid environments. *Remote Sensing* 13(6):1047.

Amine, K.M., C.P.Champagne, S.Salmieri, M. Britten, D. St-Gelais, P. Fustier, M. Lacroix. 2014. Effect of palmitoylated alginate microencapsulation on viability of Bifidobacterium longum during freeze-drying. *LWT Food Science Technology* 56: 111–117.

Ashraf, A.M., T. Raghavan, and S.N. Begam. 2021. Superabsorbent polymers (SAPs) hydrogel: Water saving technology for increasing agriculture productivity in drought-prone areas: A review. *Agricultural Reviews* 42(2):183-189.

Blake, G.R. and K.H. Hartge. 1986. Bulk density. p. 363-375. In: Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods, Agronomy Monograph No. 9, 2nd Ed., A. Klute, , (ed.), American Society of Agronomy/Soil Science Society of America, Madison, WI.

Busari, M.A., S.S. Kukal, A. Kaur, R. Bhatt, and A.A. Dulazi. 2015. Conservation tillage impacts soil, crop, and the environment. *International Soil and Water Conservation Research* 3(2):119-129.

Canbolat, M. 2019. Farklı agregat büyüklük fraksiyonlarında nem değişimi ve agregat büyüklüğünün bazı nem karakteristiklerine etkisi. *Atatürk Üniversitesi Ziraat Fakültesi Dergisi* 30(1):73-81.

Cassel, D.K. and D.R. Nielsen. 1986. Field capacity and available water capacity. p. 901-926. In: Methods of Soil Analysis. Part 1 Physical and Mineralogical Methods, A. Clute, (ed.), Agronomy Monograph No.9. *Soil Science Society of Americ*a. Madison, WI.

Chang, L., L. Xu, Y. Liu, and D. Qiu. 2021. Superabsorbent polymers used for agricultural water retention. *Polymer Testing* 94:107021

Chartzoulakis, K. and M. Bertaki. 2015. Sustainable water management in agriculture under climate change. *Agriculture and Agricultural Science Procedia* 4:88-98.

Dowdy S. and S. Weardin. 1983. Statistics for Research. John Wiley and Sons Inc. New York, USA.

Errahali, S., M.Chtouki, S. Qetrani, A. Oukarroum, M. Latifi, L. Belachemi, H.. Benyoucef and H. Kaddami. 2025. Effects of superabsorbent hydrogel on soil porosity, bulk density, and water productivity of tomato grown under drought stress in clay loam and sandy loam soils. *Journal of Soil Science and Plant Nutrition* 25: 1-20.

Fanta, G.F., R.C. Burr, W.M. Doane, and C.R. Russel. 1978. Absorbent polimers from starch and flour through graft polymerization of acrylonitrile and comonomer miztures. Starch-Starke. Verlag chemie, GmbH, D-6940.Nr.7 S:237-242.

FAO. 2022. The State of the World's Land and Water Resources for Food and Agriculture – Systems at Breaking Point. Main Report 22. Rome.

Gee, G.W., and J.W. Bauder. 1986. Particle-Size Analysis. p. 383-411. In: Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods, Agronomy Monograph No. 9, 2nd Ed. A. Klute, , (ed.), American Society of Agronomy/Soil Science Society of America, Madison, WI.

Guo, Y., J. Bae, Z. Fang, P. Li, F. Zhao, and G. Yu. 2020. Hydrogels and hydrogel-derived materials for energy and water sustainability. *Chemical Reviews* 120(15): 7642-7707.

Han, Y., X. Yu, P. Yang, B. Li, L. Xu, and C. Wang, 2013. Dynamic study on water diffusivity of soil with super-absorbent polymer application. *Environmental Earth Sciences* 69(1): 289–296.

Jain N.K., H.N. Meena, and D. Bhaduri. 2017. Improvement in productivity, water-use efficiency, and soil nutrient dynamics of summer peanut (*Arachis hypogaea* L.) through use of polythene mulch, hydrogel, and nutrient management. *Communications in Soil Science and Plant Analysis* 48(5): 549–564.

Johnson, M.S. 1984. Effect of soluble salts on water absorption by gel-forming soil conditioners. *Journal of the Science of Food and Agriculture* 35(10):1063-1066.

Kalhapure, A., R. Kumar, V.P. Singh, and D.S. Pandey. 2016. Hydrogels: a boon for increasing agricultural productivity in water-stressed environment. *Current Science* 1773-1779.

Kargar, M., R. Suresh, M. Legrand, P. Jutras, O.G. Clark, and S.O. Prasher. 2017. Reduction in water stress for tree saplings using hydrogels in soil. *Journal of Geoscience and Environment Protection* 5 (01): 27.

Klute A, and C. Dirksen. 1986. Hydraulic Conductivity and Diffusivity: Laboratory Methods. p. 687-734. In: Methods of Soil Analysis. Part 1: Physical and Mineralogical Methods, 2nd Ed., Agronomy Monograph No. 9, A. Klute(ed.), Madison, WI.

Liao, Y., H.X. Cao, X. Liu, H.T. Li, Q.Y. Hu, and W.K. Xue, 2021. By increasing infiltration and reducing evaporation, mulching can improve the soil water environment and apple yield of orchards in semiarid areas. *Agricultural Water Management* 253: 106936.

Malik, S., K. Chaudhary, A. Malik, H. Punia, M. Sewhag, N. Berkesia, M. Nagora, S. Kalia, K. Malik, D. Kumar, P. Kumar, E. Kamboj, V. Ahlawat, A. Kumar, and K. Boora. 2022. Superabsorbent polymers as a soil amendment for increasing agriculture production with reducing water losses under water stress conditions. *Polymers* 15(1):161.

Mandal, U.K., K.L. Sharma, K. Venkanna, G.R. Korwar, and K.S. Reddy. 2015. Evaluating hydrogel application on soil water availability and crop productivity in semiarid tropical red soil. *Indian Journal of Dryland Agricultural Research and Development* 30(2): 1-10.

McLean, E.O. 1983. Soil pH and lime requirement. p. 199-224. In: Methods of Soil Analysis. Part 2:Chemical and Microbiological Properties, American Society of

Agronomy, A.L. Page, (ed.), *Soil Science Society of America*.

Mikkelsen, R.L. 1994. Using hydrophilic polymers to control nutrient release. *Fertilizer Research* 38(1): 53-59.

Montesano, F.F., A. Parente, P. Santamaria, A. Sannino, and F. Serio. 2015. Biodegradable superabsorbent hydrogel increases water retention properties of growing media and plant growth. *Agriculture and Agricultural Science Procedia* 4: 451-458.

Narjary, B., P. Aggarwal, A. Singh, D. Chakraborty, and R. Singh. 2012. Water availability in different soils in relation to hydrogel application. *Geoderma* 187: 94–101.

Narjary, B., P. Aggarwal, S. Kumar, and M.D. Meena. 2013. Significance of hydrogel and its application in agriculture. *Indian Farming* 62(10): 15-17.

Nazarli, H., M.R. Zardashti, R. Darvishzadeh, and S. Najafi. 2010. The effect of water stress and polymer on water use efficiency, yield, and several morphological traits of sunflowers under greenhouse conditions. *Notulae Scientia Biologicae* 2(4): 53-58.

Neethu, T.M., P.K. Dubey, and A.R. Kaswala. 2018. Prospects and applications of hydrogel technology in agriculture. *International Journal of Current Microbiology and Applied Sciences* 7(5):3155-3162.

Nelson, D.W. and L.E. Sommers. 1982. Total Carbon, Organic Carbon and Organic Matter. P. 539-580. Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties, Agronomy Monograph No. 9. A. L. Page (ed.), , Madison, WI, USA

Nelson, R.E. 1982. Carbonate and gypsum. P. 181-197. Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties, Agronomy Monograph No. 9. A. L. Page (ed.), Madison, WI, USA.

Nirmala, A. and T. Guvvali. 2019. Hydrogel/superabsorbent polymer for water and nutrient management in horticultural crops. *International Journal of Chemical Studies* 7(5):787-795.

Patra, S. K., R. Poddar, M. Brestic, P.U., Acharjee, P. Bhattacharya, S. Sengupta, P. Pal, N. Bam, B. Biswas, V. Barek, P. Ondrisik, M. Skalicky, and A. Hossain. 2022. Prospects of hydrogels in agriculture for enhancing crop and water productivity under water deficit conditions. *International Journal of Polymer Science* 2022(1):4914836

Peppas, N. 2000. Hydrogels in pharmaceutical formulations. *European Journal of Pharmaceutics and Biopharmaceutics* 50(1): 27–46.

Pereira, L. S., T. Oweis, and A. Zairi. 2002. Irrigation management under water scarcity. *Agricultural Water Management* 57(3):175-206.

Reynolds, W. D. 2018. An analytic description of field capacity and its application in crop production. *Geoderma* 326:56–67.

Rhoades, J.D. 1982. Soluble salts. P. 149-157. Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties, Agronomy Monograph No. 9. A. L. Page (ed.), , Madison, WI, USA.

Riad, G., S. Youssef, N. Abu El-Azm, and E. Ahmed. 2018. Amending sandy soil with biochar or/and superabsorbent polymer mitigates the adverse effects of drought stress on green peas. *Egyptian Journal of Horticulture* 45(1): 169–183.

Richards, L. A. 1954. Diagnosis and Improvement of Saline and Alkaline Soils, USDA handbook. 78(2):154.

Rigas, F., E. Sachini, G. Chatzoudis, and N. Kanellopoulos. 1999. Effects of a polymeric soil conditioner on the early growth of sunflowers. *Canadian Journal of Soil Sci*. 79(1): 225-231.

Ruehlmann, J. and M. Körschens. 2009. Calculating the effect of soil organic matter concentration on soil bulk density. *Soil Science Society of America Journal* 73(3): 876-885.

Saha, A., S. Sekharan, and U. Manna. 2020. Superabsorbent hydrogel (SAH) as a soil amendment for drought management: A review. *Soil and Tillage Research* 204:104736.

Seybold, C.A. 1994. Polyacrylamide review: Soil conditioning and environmental fate. *Communications in Soil Science and Plant Analysis* 25(11-12): 2171-2185.

Shahid, S.A., A.A. Qidwai, F. Anwar, I. Ullah, and U. Rashid. 2012. Improvement in the water retention characteristics of sandy loam soil using a newly synthesized poly (acrylamide-co-acrylic acid)/AlZnFe2O4 superabsorbent hydrogel nanocomposite material. *Molecules* 17(8): 9397-9412.

Skrzypczak, D., K. Mikula, N. Kossińska, B. Widera, J. Warchoł, K. Moustakas, K. Chojnacka, and A. Witek-Krowiak. 2020. Biodegradable hydrogel materials for water storage in agriculture-review of recent research. *Desalination and Water Treatment* 194:324-332.

Song, J.H., Y. Her, X. Yu, Y. Li, A. Smyth, and W. Martens-Habbena. 2022. Effect of information-driven irrigation scheduling on water use efficiency, nutrient leaching, greenhouse gas emission, and plant growth in South

Florida. *Agriculture, Ecosystems & Environment* 333:107954.
Suresh, R., S.O. Prasher, R.M. Patel, Z. Qi, E. Elsayed, T. Schwinghamer, and A.M. Ehsan. 2018. Super absorbent polymer and irrigation regime effects on growth and water use efficiency of container-grown cherry tomatoes. *Transactions of the ASABE* 61(2): 523-531.
Takahashi, M., I. Kosaka, and S. Ohta. 2023. Water retention characteristics of superabsorbent polymers (SAPs) used as soil amendments. *Soil Systems* 7(2): 58.
Twarakavi, N.K.C., M. Sakai, and J. Šimunek. 2009. An objective analysis of the dynamic nature of field capacity. *Water Resources Research* 45:W10410.
Wang, S., H. Wang, Y. Zhang, R. Wang, Y. Zhang, Z. Xu, G. Jia, X. Wang, and J. Li. 2018. The influence of rotational tillage on soil water storage, water use efficiency and maize yield in semi-arid areas under varied rainfall conditions. *Agricultural Water Management* 203: 376-384.
Wu, Y., S. Li, and G. Chen. 2023. Hydrogels as water and nutrient reservoirs in agricultural soil: a comprehensive review of classification, performance, and economic advantages. *Environment, Development and Sustainability* 1-33.
Ziolkowska, J.R. 2015. Shadow price of water for irrigation-A case of the High Plains. *Agricultural Water Management* 153:20-31.