Effects of hydrogel amendment on water storage of sandy loam and loam soils and seedling growth of barley, wheat and chickpea

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ABSTRACT

The hydrogel amendments may improve seedling growth and establishment by increasing water retention capacity of soils and regulating the plants available water supplies, particularly under arid environments. The effects of different levels of a locally prepared hydrogel were studied on the moisture properties of sandy loam and loam soils (fine-loamy, mixed, hyperthermic Typic Haplargids, USDA, Luvic Yermosol, FAO) and on growth response of three plant species, viz. barley (*Hordeum vulgare* L.), wheat (*Triticum aestivum* L.) and chickpea (*Cicer arietinum* L.). Water absorption by gel was rapid and highest in distilled water and was inhibited by an increase in water salinity. The addition of 0.1, 0.2 and 0.3% hydrogel increased the moisture retention (θr) at field capacity linearly ($r = 0.988$) and thus the amount of plant available water significantly in both sandy loam and loam soils compared to the untreated soils. Seed germination of wheat and barley was not affected but seedling growth of both species was improved by the gel amendment. In loam soil, seed germination of chickpea was higher with 0.2% gel and seedling growth increased with increase in gel level compared with control conditions. The hydrogel amendment caused a delay by 4–5 days in wilting of seedlings grown in both soils compared with control conditions. The hydrogel amendment was effective in improving soil moisture availability and thus increased plant establishment. However, the varied responses of plant species in sandy loam and loam soils warrant further studies on the behaviour of different soil types with gel amendments.

Keywords: soil hydrogel amendment; soil moisture properties; seed germination; seedling growth; water absorption

Synthetic polymers in the form of crystals or tiny beads available under several trade names such as super absorbent polymers, root watering crystals and drought crystals are collectively known as hydrogels. They have enormous capacity to absorb water when it comes by and make it available to plants over time. Many studies related to application of hydrogels in horticulture have been reported (Henderson and Hensley 1985, Ingram and Yeager 1987, Wang and Boogher 1987, Wang and Gregg 1990). The addition of hydrogel at the rate of 2 g/kg increased the water holding capacity of coarse sand from 171 to 402% (Johnson 1984a). Further, hydrogel addition improved water storage properties of porous soils and resulted in the delay and onset of permanent wilting percentages under intense evaporation. An increase in water holding capacity due to hydrogel significantly reduced the irrigation requirement of many plants (Taylor and Halfacre 1986).

Seed germination and establishment are critical phases in plant growth and development. The establishment of crop cover is often restricted due to low moisture available in coarse textured soils, particularly in arid environments. The application of hydrogels is an important practice to assist plant growth by increased water retention by sandy soils and its availability to plants in dry regions. The amendment with hydrogel is known to improve seed germination and seedling growth in several species. Ahmed and Verplancke (1994) reported an improvement in germination and biomass production of Trifolium, lettuce and ryegrass in dune sand with gel amendment compared to control. Seedling emergence rate and dry seedling weight in lettuce, tobacco and cotton increased in soil amended with hydrogel (Wallace and Wallace 1986). Woodhouse and Johnson (1991) have shown varying degrees of improvement in the germination and establishment of different plant species. Despite various beneficial effects of hydrogel addition, some studies have shown little or no benefit with hydrogel addition (Conover and Poole 1976, James and Richards 1986, Ingram and Yeager 1987, Wang 1987). The variations in hydrogel effects and plant responses seem due to differences in the type of hydrogels and soils. Therefore, information regarding the effects of a given gel type and species responses under specific soil conditions is necessary before field applications. Furthermore, timely supplies and the cost of hydrogel are important factors in the success and economics of projects envisaging the rehabilitation of sandy and arid areas through increased plant establishment and productivity in Pakistan and elsewhere. The objectives of the present study were to determine the effects of different levels of a locally prepared hydrogel on moisture properties of two soils and on growth response of three plant species (barley, wheat and chickpea) in soils amended with hydrogel.

MATERIAL AND METHODS

Gel preparation. Gel was prepared at laboratory scale by polymerisation of acrylamide (N,N-methyl-bis-acrylamide) and mixed Na and K salts of acrylic acid. The mixture was deaerated with nitrogen gas and placed in thermostatic bath circulator at 78°C for 5 hrs. The swollen gel was washed with pure acetone/water (60/40) solution for five days and was deswelled by soaking in pure acetone. The gel was dried in oven at 65°C till constant weight was achieved.

Water uptake by hydrogel. A portion of the gel was powdered (< 0.1 mm) in a ball mill MM200 type. One gram each of crystals (< 3 mm) and powder gel was placed over filter paper in individual plastic pots with a hole in the bottom. The pots were placed in distilled water (electrical conductivity EC = 0.0084 dS/m), tap water (EC = 0.759 dS/m) and saline water (EC = 5.09 dS/m). Gels were immersed in water for 4 hrs, drained for 4 hrs, and their weights were recorded.

Soils used in the experiment. Two soils, sandy loam (sand 78%, silt 9%, clay 13%) and loam (sand 45%, silt 33%, clay 22%) were collected from 25 cm depth at two sites at the experimental farm of the Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad (31°20′N, 73°05′E), Pakistan. The soils belong to the Hafizabad series (fine-loamy, mixed, hyperthermic Typic Haplargids, USDA, Luvic Yermosol, FAO). The soils were air dried, ground, and passed through 2 mm sieve. Soil texture was determined by sedimentation technique described by Day (1965). Electrical conductivity (EC) and pH of saturated paste extracts of soil were determined by WTW conductivity meter LF-530 and Corning pH meter 130, respectively. Some characteristics of the soils are presented in Table 1.

Effects of hydogel on moisture properties of soils. Fine hydrogel (0.1 mm) was mixed at the rate of 0.1, 0.2 and 0.3% in the soil. The 200 g portions of each soil mixture were filled in 300 cm^3 plastic pots with a filter paper placed at the bottom with a small hole. Triplicate pots of each soil mixture were saturated with tap water by placing in containers for 24 hrs. The pots were raised to drain out the excess water gravimetrically. The pots were placed under laboratory conditions at 25°C. The weights of the pots were recorded three to four times weekly until no detectable weight loss was observed. The pots were saturated again and the procedure was repeated for the 2nd wetting-drying cycle.

Effects of hydrogel on seed germination and seedling growth. The hydrogel was mixed at the rate of 0.1, 0.2 and 0.3% in air-dried soil. The 200 g portions of each of the soil mixtures were filled in 300 cm^3 plastic pots with a filter paper placed at the bottom with a small hole. Four seeds each of barley (*Hordeum vulgare*), wheat (*Triticum aestivum*) and chickpea (*Cicer arietinum*) were sown in triplicate pots for each hydrogel level of both soils. Triplicate pots of each soil without hydrogel and with different levels of gel were kept as a check (control). The soil was saturated with tap water by placing the pots in trays containing water for 24 hrs. The pots were raised to drain out the excess water gravimetrically. Pots were placed in a growth chamber at 28 ± 2°C. Pots were weighed on alternate days till no detectable weight loss was observed. Germination was recorded by counting the germinated seeds up to two weeks. Emergence of shoot was taken as an indicator of seed germination. No water was applied except the initial saturation of the pots. When the signs of wilting of seedlings appeared for the first time, the experiment was terminated. The plant shoots were harvested at ground level and shoot length and fresh weight were recorded. The plant material was dried at 70°C for 24 hrs and dry mass was determined. The soils

Table 1. Some characteristics of soils used (values are means of 3 replicates)

Parameter	Soil type	
	sandy loam	loam
Sand (%)	78	45
Silt (%)	9	33
Clay (%)	13	22
Electrical conductivity (dS/m)	1.33	0.5
pH	7.0	7.6
Sodium adsorption ratio	1.18	1.36
Ca^{2+} + Mg^{2+} (mmol)	4.8	1.55
Na^+ (mmol)	2.6	1.7
K^+ (mmol)	0.8	0.3
HCO_3^- (mmol)	1.4	1.7
Cl^- (mmol)	2.9	1.6

were saturated again after harvesting the plants and soil moisture retention was determined for three weeks to investigate the effects of hydrogel for the second wet and dry cycle.

Statistical analysis. The data was subjected to the analysis of variance (ANOVA). The *F*-test was used to identify the treatments main effects and interactions followed by Duncan's Multiple range test at the 0.05 probability level (Steel and Torrie 1980). The data was also subjected to simple linear and non-linear regression analyses. The regression coefficient (*b*) and correlation coefficient (*r*) were verified at the $P \leq 0.05$ and 0.01 levels.

RESULTS

Water absorption by hydrogel

Water absorption by gel was rapid in distilled water and reached to the maximum in 4, 7 and 12 hrs in distilled, tap and saline water, respectively. Water absorption by gel decreased with an increase in water salinity (Figure 1) with maximum absorption in distilled water (505 g/g) followed by tap water (212 g/g) and saline water (140 g/g) during 1st hydration cycle. The water absorption by gel at three salinity levels decreased slightly but non-significantly in subsequent second and third hydration cycles (Figure 1).

Soil moisture properties

In general, the addition of hydrogel increased the moisture content at field capacity of both sandy loam and loam soils. In sandy loam soils the addition of 0.1, 0.2 and 0.3% hydrogel increased field capacity by 17, 26 and 46%, respectively, compared with untreated soil. In loam soil, an increase of 23, 36 and 50% in soil field capacity was observed with addition of 0.1, 0.2 and 0.3% hydrogel compared to control (Figure 2). The addition of hydrogel increased the moisture retention (θr) at field capacity linearly in sandy loam (θr = 0.457 gel% + 0.287) and loam (θr = 0.558 gel% + 0.353) with *r*-value of 0.988*. The amount of plant available soil water (AW) increased significantly and linearly in both soils with the addition of hydrogel compared with untreated soils (Figure 2).

The application of hydrogel increased the soil water storage in both sandy loam and loam soils compared with control. The amendment with hydrogel slowed the rate of soil moisture loss that caused a delay in wilting of seedlings grown in both soils (Figures 3 and 4). The onset of permanent wilting point (PWP) was delayed by 1.5, 2 and 5 days in sandy loam soil with increase in hydrogel concentration 0.1, 0.2 and 0.3%, respectively (Figure 3). In loam soil, the onset of PWP level was delayed by 4 days at the three applied hydrogel concentrations (Figure 4).

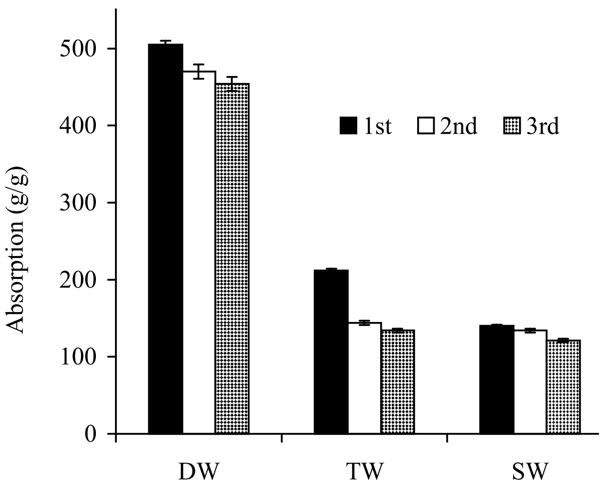
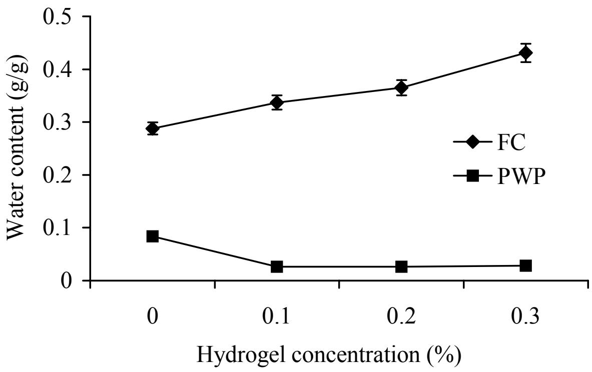


Figure 1. Absorption of distilled water (DW), tap water (TW) and saline water (SW) by gel during 1st, 2nd and 3rd wetting and drying cycle



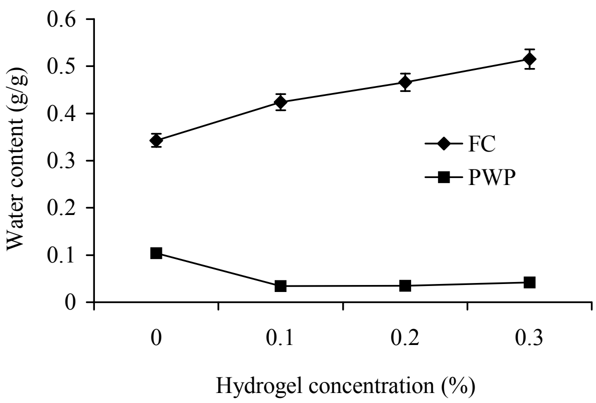


Figure 2. Effects of hydrogel levels on water content at field capacity and permanent wilting point in sandy loam (above) and loam (below) soils; the difference between water content at field capacity and permanent wilting point shows the total plant available water

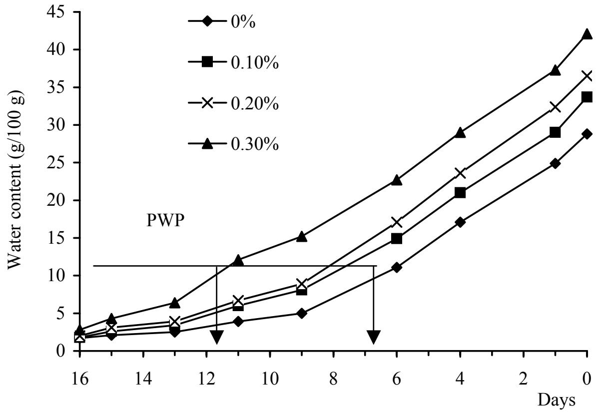


Figure 3. Effects of hydrogel concentration on water storage of sandy loam soil; PWP refers to permanent wilting point and the arrows indicate the days for onset of PWP at different hydrogel levels

Seed germination and seedling growth

Seed germination of wheat and barley was not affected by the addition of hydrogel in either sandy loam or loam soils. However, overall seed germination percentage of barley was slightly higher in sandy loam than in loam soil irrespective of the gel treatment. Seed germination of wheat was similar in the two soils (Table 2). Seedling growth of both species, barley and wheat, was enhanced by the addition of gel in the soils. Shoot length of barley was significantly higher at 0.3% gel compared with other gel levels or control. However, the shoot fresh and dry weights increased significantly with the increase in gel level in the soil. The overall mean dry and fresh weights of barley shoots were comparable in both sandy loam and loam soils (Table 2).

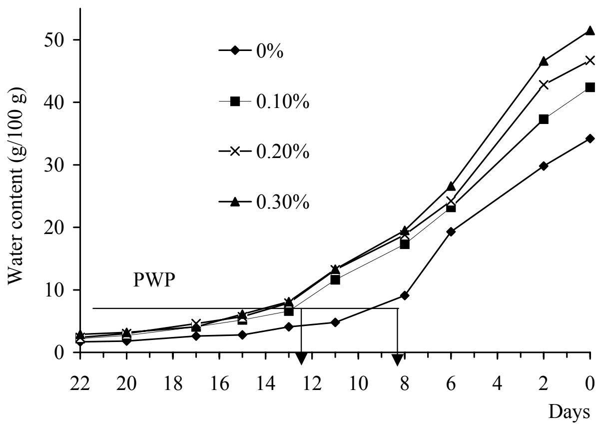


Figure 4. Effects of hydrogel concentration on water storage of loam soil; PWP refers to permanent wilting point and the arrows indicate the days for onset of PWP at different hydrogel levels

Shoot length of wheat was significantly increased with the addition of gel compared with control. The effects of hydrogel treatments on shoot biomass were not consistent; however, the addition of 0.3% gel in soil significantly increased the fresh and dry weights of wheat shoots (Table 2). Further, the effects of gel levels in both soils were not different and seed germination and seedling growth of wheat were similar in sandy loam and loam soils. The effects of hydrogel treatment in sandy loam soil on seed germination or seedling growth of chickpea were not consistent. Seed germination was significantly higher in 0.2% gel treatments compared with control. The other levels of hydrogel did not have significant effects. The higher hydrogel levels (0.2 and 0.3%) increased seedling growth compared with control but not significantly so (Table 3). The chickpea seeds did not germinate in loam soil due to high soil water content; therefore, the results of sandy loam soil are reported.

DISCUSSION

Seed germination and seedling development are critical phases in early growth and establishment of any plant species. The successful establishment of agricultural crops depends on moisture availability and is often restricted by poor soil moisture level particularly in arid and semi-arid environments. The use of soil conditioners has been suggested to improve moisture retention by coarse soils (McGuire et al. 1978). The gel used in the present study had high water absorption during the first wetting and it decreased during subsequent wetting cycles and by an increase in salt content in the water used (Figure 1). The chemicals and ions present in irrigation water can adversely affect the water retention by hydrogels (Johnson 1984b, Asady et al. 1985). Water retention was significantly lower when tap water and saline water was used compared to distilled water. As the use of distilled water for irrigation is out of question, we used the tap water in the experiments on water retention by soil.

The amendment with hydrogel increased the field capacity of both sandy loam and loam soils and thus the plants available water (Figure 2). Such increase in water content at field capacity has been reported for several soil types (Johnson 1984a, Taylor and Halfacre 1986, Kos and Le tan 2003). While the amount of plant available water is increased by hydrogel amendment, the period of its availability is also important for plants and is determined by the rate of evaporation from the soil. As determined from the water storage curves (Figures 3 and 4), the evaporation losses

Table 2. Effect of different levels of hydrogel (in %) on seed germination and seedling growth (15 days) of wheat (*Triticum aestivum*) and of barley (*Hordeum vulgare*) in sandy loam and loam soils

	Wheat			Barley		
	sandy loam	loam	mean (gel)	sandy loam	loam	mean (gel)
Seed germination (%)						
0	100 a	75 a	87.5 a	91.6 a	83.3 a	87.5 a
0.1	100 a	75 a	87.5 a	100 a	66.6 a	83.3 a
0.2	75 a	66.6 a	70.8 a	66.6 a	100 a	83.3 a
0.3	91.6 a	75 a	83.3 a	91.6 a	100 a	95.8 a
Mean (soil)	91.6 A	75 A		87.5 A	87.5 A	
Shoot length (cm)						
0	16.2 b	16.0 b	16.1 b	16.9 c	20.8 b	18.9 c
0.1	16.9 ab	15.8 b	16.4 b	20.2 bc	22.3 ab	21.3 b
0.2	18.3 ab	16.1 b	17.2 b	21.2 ab	21.9 ab	21.6 b
0.3	19.5 a	20.2 a	19.8 a	24.4 a	22.9 a	23.6 b
Mean (soil)	17.7 A	17.0 A		20.7 A	21.9 B	
Shoot fresh weight (mg)						
0	71 c	72 b	72 d	180 b	193 a	187 b
0.1	111 b	92 ab	102 c	212 ab	217 a	215 b
0.2	151 a	105 ab	128 b	217 ab	211 a	214 b
0.3	187 a	126 a	157 a	246 a	226 a	236 a
Mean (soil)	130 A	99 B		214 A	212 A	
Shoot dry weight (mg)						
0	15 b	13 b	14 c	14 b	16 b	15 c
0.1	17 b	14 b	15 bc	18 ab	18 b	18 b
0.2	20 a	13 b	16 b	18 ab	16 b	17 bc
0.3	21 a	18 a	20 a	23 a	20 a	22 a
Mean (soil)	18 A	14 B		19 A	18 A	

Means followed by different letters (lower case) in a column differ significantly at $P \leq 5\%$ level

The different letters (capital) following mean (soil) values indicate significant differences between sandy loam and loam soils

from untreated soils were rapid compared with soil amended with hydrogel. The reductions in evaporation losses with hydrogel addition were more pronounced in sandy loam soil compared with loam soil. As a result, the onset of a permanent wilting point was delayed by 4–5 days. Such an increase in time to wilt reduced the water requirements of plants (Ghering and Lewis 1980, Taylor and Halfcare 1986).

Seed germination of wheat and barley was not affected, but seedling growth of both species was enhanced by gel amendment (Table 2). In contrast, the hydrogel amendment did not affect seedling growth of chickpea (Table 3). The increased water availability with hydrogel amendments is known to improve seed germination and seedling growth, however there are variations in the response of different species to polymer (hydrogel) products (Woodhouse and Johnson 1991, Ahmad and Verplancke 1994). Seedling emergence and growth of crop plants increased in soil amended with hydrogel (Wallace and Wallace 1986). However, other studies have shown little or no beneficial effect of hydrogel addition in the soil (James and Richards

Table 3. Effect of different levels of hydrogel on seed germination and seedling growth (15 days) of chickpea (*Cicer arietinum*) in sandy loam soil

Hydrogel level (%)	Seed germination (%)	Shoot length (cm)	Shoot fresh weight (mg)	Shoot dry weight (mg)
0	58.3 b	17.0 a	394 a	46 a
0.1	50.0 b	13.7 a	321 a	57 a
0.2	91.6 a	15.8 a	423 a	62 a
0.3	75.0 ab	21.4 a	634 a	77 a

Means followed by different letters in a column differ significantly at $P \leq 5\%$ level

1986, Ingram and Yeager 1987, Wang 1987). The effects of hydrogel amendment also differed with soil type and plant species. Seedling growth of barley was higher in sandy loam than in loam soil but no such effect was observed in wheat (Table 2). McGuire et al. (1978) reported that the effects of soil conditioners on coarse sand and sandy loam soil and turfgrass growth and quality were inconsistent.

The results of our studies showed that the locally prepared hydrogel has reasonably high water absorption capacity that was retained in subsequent wetting and drying cycles. The addition of the hydrogel improved the water storage of soils and enhanced seedling growth. The use of hydrogel amendments as cultural practice will be useful for increased plant establishment in drought prone environments. However, the variations in the influence of hydrogel addition on soil moisture retention properties and in the response of different species warrant further investigations for the recommendations of specific hydrogel and soil types. Nevertheless, the hydrogel used in this work has proven to have water absorption comparable to commercially sold products.

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ABSTRAKT

Vliv přídavku hydrogelu na zadržení vody v písčité a jílovité půdě a růst semenáčků ječmene, pšenice a cizrny

Přídavky hydrogelu mohou zlepšit vzcházení a růst semenáčků zvýšením retenční vodní kapacity půd a úpravou zásoby přístupné vody v půdě, zejména v aridních podmínkách. Byl sledován vliv různých dávek laboratorně připraveného hydrogelu na vlhkostní charakteristiky písčité a jílovité půdy (Luvic Yermosol) a na růst tří rostlinných druhů: ječmene (*Hordeum vulgare* L.), pšenice (*Triticum aestivum* L.) a cizrny (*Cicer arietinum* L.). Absorpce vody gelem probíhala rychle, nejvyšší byla v destilované vodě, zvýšené množství solí ve vodě ji snižovalo. Přídavek 0,1; 0,2 a 0,3% hydrogelu vedl k lineárnímu růstu vlhkosti při polní vodní kapacitě (r = 0,988), a zvyšoval tak významně množství rostlinám přístupné vody ve srovnání s neošetřenou půdou u obou sledovaných typů půd. Klíčení semen pšenice a ječmene nebylo přídavkem hydrogelu ovlivněno, avšak růst semenáčků obou rostlin se zlepšil. Klíčení cizrny v jílovité půdě bylo vyšší při přídavku 0,2% gelu a růst semenáčků se zvyšoval s rostoucí dávkou hydrogelu ve srovnání s kontrolní variantou. Přídavek hydrogelu rovněž vedl k pozdějšímu vadnutí semenáčků o 4 až 5 dnů. Přídavek hydrogelu byl účinný, pokud se týká zlepšení přístupnosti půdní vlhkosti, a zvýšil tak vzcházení a růst semenáčků. Odlišné odezvy rostlinných druhů v jílovité a písčité půdě však vyžadují další studium reakce různých půdních druhů na přídavky hydrogelu.

Klíčová slova: půdní hydrogelové přídavky; vlhkostní charakteristiky půdy; klíčení semen; růst semenáčků; poutání vody

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