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Potentials of hydrogels in rainfed soil to conserve soil moisture and fertility to maximize the wheat yield

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Abstract

The availability of limited irrigation water in rainfed regions is the most challenging constraint to harvest the maximum agronomic benefits. The adaptation of smart water-saving techniques is desperate to combat soil moisture stress and soil quality. The application of hydrogels to conserve soil moisture and plant nutrients to satisfy the crop needs is considered one of the most efficient strategies. Keeping in view the peculiar benefits of hydrogels, an experiment was planned and executed in rainfed areas to quantify the potential benefits of hydrogels for the conservation of soil moisture and restoration of soil fertility under wheat production compared with various conventional soil amendments. The treatments were: T_1 (Control), T_2 Farmyard manure @ 2500 kg ha^{-1}, T_3 Compost @ 750 kg ha^{-1}, T_4 Gypsum @ 1000 kg ha^{-1}, T_5 Hydrogel @ 15 kg ha^{-1}. The findings of this experiment revealed that soil moisture retention increased from 27 to 73% compared with control (untreated soil) and the application of soil amendments enhanced the soil NO_3-N (6 to 24 mg kg^{-1}), P_2O_5 (4.75 to 11 mg kg^{-1}), and K_2O (93.50 to 115.25 mg kg^{-1}), respectively, by farmyard manure, compost, gypsum and hydrogel under specified doses. The wheat grain yield increased from 2165 to 3760 kg ha^{-1}. This study has provided preliminary results regarding the use of hydrogels in a field experiment in rainfed areas of Pakistan. Further studies are required to investigate the performance of various hydrogels under variable environments before recommending to the farmers.

Keywords: Soil amendments, water use efficiency, fertilizer use efficiency, water holding capacity; rainfed areas

Introduction

The agricultural production in rainfed areas is confronted with many challenges including uncertain frequency and the distribution of rainfall. The success of crops largely depends upon the water supply through rains otherwise soil moisture shortage will result in drought stress (Abdelfattah, 2013). Various management strategies including the conventional soil amendments have been tested but could not offer a sustainable solution to defer moisture stress and fertility depletion. The most sustainable solution of all these issues is the prolonged retention of rainwater through appropriate water conservation techniques to ensure the crop survival (Bhardwaj *et al.,* 2007) since the limited water supply in rainfed areas is the main constraint to achieve the successful crop (Han *et al.,* 2018). The moisture deficiency accelerates the decomposition of soil organic matter causing poor water holding capacity and nutrient use efficiency (Mandal *et al*., 2011). The traditional approaches including the addition of a large quantity of organic biomass are practiced but the adoption of such practices on large scale is not viable (Ankenbauer and Loheide, 2017; Minasny and McBratney, 2018).

Several soil amendments such as gypsum, organic materials, and hydrogels, etc. have been evaluated by the researchers to conserve the profile soil moisture and plant nutrients but most of these could not gain widespread acceptance due to their short-term benefits and high cost. However, many studies have proved that the addition of hydrogels as a soil amendment is effective in enhancing soil water-holding-capacity by minimizing the excessive water drainage and evaporation (Cannazza *et al.,* 2014; Guilherme *et al.,* 2015). The hydrogels are channels of polymers having the ability to hold large quantities of water (Azevedo *et al.,* 2016). The incorporation of a precise number of hydrogels in the soil can improve water holding capacity; minimize the evapotranspiration and, mitigate the drought stress symptoms (Li *et al*., 2018). The enhanced availability

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of water may assist to defer the water stress condition during long periods of drought. It is assumed that water release through the network of hydrogel will develop additional space in the soil which will facilitate the root growth and water penetration for long-term storage. Additionally, this stored water will restrict nutrient losses through leaching and percolation, consequently, extending the supply of water and nutrients for an extended period (Karimi and Naderi, 2007; Bagheri and Afrasiab, 2013; Pattanaaik *et al.*, 2015). Furthermore, the addition of hydrogels may enhance the fertilizer use efficiency in soil by extending the nutrient release period (Zhang *et al.*, 2006).

Hydrogels can be categorized into three groups of a polymer including i) Starch polyacrylonitrile graft polymers (starch copolymers), ii) Vinyl alcohol-acrylic acid copolymers (polyvinyl alcohols), and iii) Acrylamide sodium acrylate copolymers-cross–linked polyacrylamides. Hydrogel-forming natural polymers include proteins such as collagen and gelatin and polysaccharides such as starch, alginate, and agarose. Synthetic polymers that form hydrogels are traditionally prepared by using chemical polymerization methods (Ahmed, 2015). The hydrogel selected for this study is known as polyacrylamide (Qemisoyl) which can absorb and retain a large amount of water along with nutrients for the uptake of crops. One gram of this hydrogel can absorb up to 500 mL of water and is recommended to be applied once and remain functional for 4-7 years in the soil (Monning, 2005).

The topography of the area under this study is sloppy which limits the water infiltration and storage due to excessive runoff. Several scientists have revealed that the slope gradient can increase soil erosion due to poor infiltration rate and enhance the surface run off (Neethu *et al.*, 2018). Pakistan is an agricultural country with having diverse climate and about two-thirds of its lands are categorized as arid facing the high temperature and low rainfall (Chaudhry and Rasul, 2004). Wheat is the most important crop being the staple food, but it faces at least two dry spells because of uncertain rainfall under the changing climate scenario. It is predicted that Pakistan will receive lesser winter rains in the coming times which may delay the sowing of wheat under rainfed areas of Pakistan. The sowing of wheat is carried out in October to November, but the weather forecast has predicted a reduction in winter rains (Hanif and Ali, 2014). An ample supply of irrigation water for crops during the growth and development of crops is compulsory for the successful crop to stand to ensure food security in the region (Iqtidar *et al.*, 2006). So, the innovative approaches to enhance water retention especially for wheat production under rainfed conditions are needed desperately to achieve the desired yield goals. Many studies across the world have proved the potential benefits of hydrogels as a soil amendment but there is no information available in rainfed areas of Pakistan regarding the use of hydrogels especially for field crops. So, there is a need for extensive research to investigate the potential benefits of hydrogels and the standardization application rate.

Therefore, considering the benefits of hydrogels and other soil conditioners and peculiar problems of rainfed areas, a field study was undertaken to compare the benefits of these soil conditioners by evaluating their impact on soil chemical properties and wheat yield.

Materials and Methods

Location

The location of the experiment selected in Fateh Jang (Attock) was situated on latitude; 33.55° N, and longitude; 72.58° E. The majority of soils of the area are prone to soil erosion, gully development, and soil moisture shortage. The climate is semi-arid to sub-tropical receiving 584 mm mean annual rainfall, out of which only 30% rainfall was received during the wheat growing season. The soils are deep having good drainage (Reconnaissance Soil Survey, Campbellpur, 1970). Soil properties at the start of the experiment are given in Table-1. Before the execution of the experiment, a composite soil sample representing the characteristics of the experimental site was collected, air-dried, and separated by 2 mm sieve. The pH and EC of soil were determined by McLean (1982), and Richards (1954), Soil organic matter by Walkley (1947), K_2O by Rhodes, 1982, P_2O_5 by Watanabe and Olsen (1965), and soil particle size by Gee and Bauder (1986).

Table-1: Soil properties at the start of experiment

Soil property	Value	Unit
pH	8.12	-
EC_e	0.76	dS m^{-1}
Bulk density	1.59	g cm^{-3}
O.M	0.87	%
P	3.8	mg kg^{-1}
K	93	mg kg^{-1}
Soil texture	Sandy loam	-

Experiment

The study was carried out during the autumn season, 2011-12 to 2014-15. All the treatments were directly incorporated in the soil before sowing of wheat during the 1st week of November. The experiment was comprised of five treatments: T_1 (Control), T_2 FYM @ 2500 kg ha^{-1}, T_3

Compost @ 750 kg ha^{-1}, T_4 Gypsum @ 1000 kg ha^{-1}, and T_5 Hydrogel @ 15 kg ha^{-1}. The experiment was laid in an RCBD arrangement with 3 replications. During the first year of study, half rate of recommended NPK (120, 80, 60 kg ha^{-1}) was applied in hydrogel plots and full recommended dose of NPK in gypsum plots but in the following years, full doses of recommended NPK were applied before sowing of wheat in the form of urea, di-ammonium phosphate, and sulfate of potash. However, the amendments (gypsum and hydrogels) were applied once at the start of the study considering their long-term efficiency in soil. Wheat variety *BARS-2010* was sown every year. All the recommended agronomic and cultural practices were carried out when and where required. The experiment was conducted in rainfed conditions and no supplemental irrigation was applied except natural precipitation. The plots were harvested manually during the 1st week of May and 1 m^2 wheat crop sample was collected from every treatment to determine grain yield. A composite soil sample consisting of three sub-samples was also collected from each treatment for the determination of physicochemical properties. The data was analyzed statistically (using statistics 8.1) by LSD test at a 5% probability level (Steel *et al.*, 1997).

Soil moisture retention test

The soil was collected from 0-20 cm soil layer and dried in air. The soil was ground and passed through a 2 mm sieve and 1 kg loose soil was filled in polyvinyl chloride columns having 30 cm length and 5 cm diameter. The columns were sealed from the bottom with nylon mesh cloth and placed on sealed plastic lids having small holes to drain excess water. The columns were tapped 20 times to maintain bulk density near the field conditions. All the treatments were mixed in a 5 cm top layer following the rates described in the previous section. Then, columns were saturated with distilled water from the top. Soil moisture was monitored periodically by weighing the columns at an interval of 3 days to 30 days.

Results and Discussion

Grain yield

The impact of soil amendments on wheat grain yield is shown in Figure 1. It was observed that all soil amendments enhanced the wheat grain yield significantly compared to control. However, when we compared the soil amendments with each other, it was noticed that the mean maximum grain yield (3760 kg ha^{-1}) was recorded in T_2 while the mean minimum grain yield (2165 kg ha^{-1}) was recorded in T_1. It was estimated that overall, 42.42, 31.51, 33.91, and 34.13% increase in wheat grain yield was recorded by hydrogel, FYM, compost, and gypsum, respectively, compared with control. Additionally, it was found that hydrogel proved the best among all soil amendments by extending an increase of 15.93, 12.87, and 12.57% in wheat grain yield compared with FYM, compost, and gypsum, respectively. Probably, the increase in wheat grain production was attributed to an increase in better supply of essential nutrients after the application of soil amendments. The best results obtained due to hydrogel application confirms the findings of Eiasu *et al.* (2007) who found that application of hydrogels with fertilizers, improved the crop yield. El-Hardy *et al.* (2009) also reported a significant increase in wheat yield and investigated that the soil moisture retention extended the supply of nutrients by the hydrogels under water stress conditions which could have resulted in better crop yield. It was also found from the data of this study that the performance of other soil conditioners i.e. FYM and compost was declined with the passage of time could be due to the rapid decomposition of soil organic matter supplied by these amendments. While the performance of gypsum was ranked second after the hydrogels could be due to enhanced soil water infiltration and improved soil structure resulted in better nutrient use efficiency (Rehman *et al.*, 2013). The application of hydrogels increased the wheat grain yield, might be a result of better assimilation of carbohydrates in the ear. The ear formation is also directly related to the number of productive tillers and conducive condition for the formation of more number of productive tillers such as the increase in CO_2 assimilation rate, delay in senescence of flag leaf, and effective translocation of dry matter from source to sink which together resulted in the production of a higher number of spikes with longer spike length (Tyagi *et al.*, 2015).

Soil fertility attributes

The data of NO_3-N concentration in soil is presented in Figure 2. The data obtained in this experiment has shown that the mean maximum soil NO_3-N contents (24.25 mg kg^{-1}) were measured in T_2 followed by 15.75 mg kg^{-1} in T_4 while the mean minimum soil NO_3-N concentration (6.00 mg kg^{-1}) was noticed in T_1. The data showed that there was an increase of 75.25, 59.32, 62.02, and 46.66% after the application of hydrogel, gypsum, compost, and farmyard manure, respectively, compared to control. The best performance of hydrogel treatment could be due to the fact that hydrogel might have entrapped the soil N from the soil solution which has minimized its losses in the form of leaching and denitrification. Hydrogel application reduced the nutrient loss and enhanced the nutrient use efficiency by reducing the need for fertilization (Ni *et al.*, 2009).

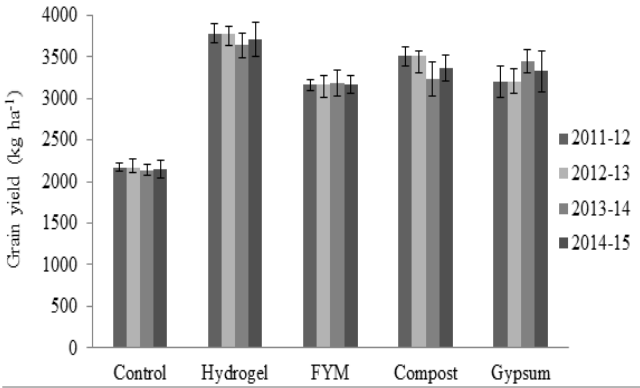

Figure 1: Impact of soil amendments on wheat grain yield

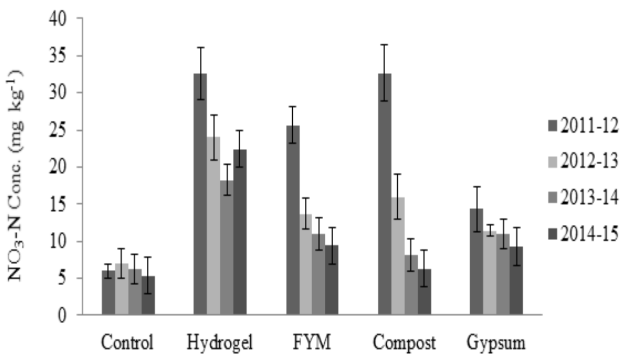

Figure 2: Impact of soil amendments on soil NO_3-N concentration

The results of this study also revealed that the incorporation of soil conditioners in soil significantly enhanced the P_2O_5 contents in all treatments compared with control however, the hydrogel performed the best and showed mean maximum P_2O_5 contents (11.00 mg kg^{-1}) followed by gypsum whereas, the mean minimum soil P_2O_5 contents (4.75 mg kg^{-1}) were recorded in T_1 (control). It was concluded that soil conditioners including hydrogel, FYM, compost, and gypsum have increased the P_2O_5 contents by 56.81, 34.48, 48.64, and 50.00%, respectively compared to control. The benefits of hydrogel addition for soil P_2O_5 retention in rainfed Pakistani soils could be attributed to a reduction in the runoff by sediment conservation since the loss of P through sediment movement is one of the major factors of low P use efficiency in these soils along with fixation of P by calcium at exchange sites. The guarantee of a sustainable supply of available soil moisture for an extended period helps in the development of soil aggregates which ensures better soil quality and P bioavailability in calcareous soils. This may also reduce the runoff by enhancing the water infiltration rate. Previous studies indicated that the addition of hydrogels @ 10 mg L^{-1} with irrigation water reduced the loss of total P by up to 92% (Lentz *et al.,* 2001), while under sprinkler irrigation polyacrylamide (PAM) reduced the loss of P applied @ 2-4 kg ha^{-1} (Bjorneberg *et al.,* 2000). It was also investigated that lower rates of PAM were more effective in irrigated agriculture, could be due to direct application with irrigation water. But, in rainfed agriculture, higher application rates of PAM (>20 kg ha^{-1}) are needed to conserve soil moisture for a longer period since using hydrogel as a soil conditioner increases the CEC, specific surface area, and available nutrient status (Rajakumar *et al.,* 2016).

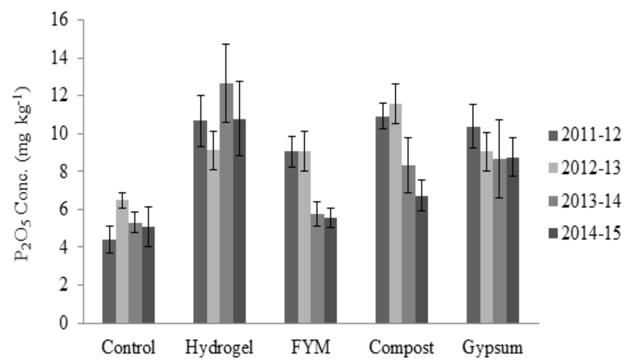

Figure 3: Impact of soil amendments on soil P_2O_5

In this experiment, the researchers found that the incorporation of soil conditioners in soil significantly improved the status of soil K_2O concentration in all treatments compared with control. However, the addition of hydrogels has revealed the best response and showed the mean maximum K_2O concentration (115.25 mg kg^{-1}) following the compost (101.25 mg kg^{-1}) whereas, the mean minimum soil K_2O contents (93.50 mg kg^{-1}) were measured in T_1 (control). It was concluded that soil conditioners including hydrogel, FYM, compost, and gypsum have increased the K_2O contents by 18.87, 5.79, 7.88, and 6.03%, respectively, compared with control. The literature review pointed out that the application of gel-forming polymers enhanced the water holding and nutrient supplying capacity of soil to improve growth and dry matter production of crops (El-Hady *et al.,* 1981).

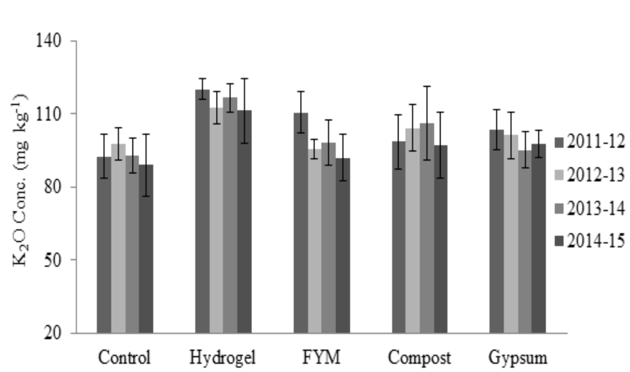

Figure 4: Impact of soil amendments on soil K_2O

Dynamics of soil water holding capacity

The experimental results presented in Figure 5, revealed that all soil conditioner enhanced the soil water holding capacity significantly. The maximum water holding capacity (73%) was recorded with T_2 under hydrogel application followed by 48% with T_4 where compost was applied. The accumulative minimum soil water holding capacity (27%) was measured with T_1 (control). However, the treatments including hydrogel, FYM, compost, and gypsum have increased the water holding capacity by 63.01, 37.20, 43.75, and 35.71%, respectively, compared to control. The comparison among soil amendments showed that the hydrogel has enhanced soil water holding capacity by 41.09, 34.24, and 42.46%, respectively, compared to FYM, compost, and gypsum, respectively.

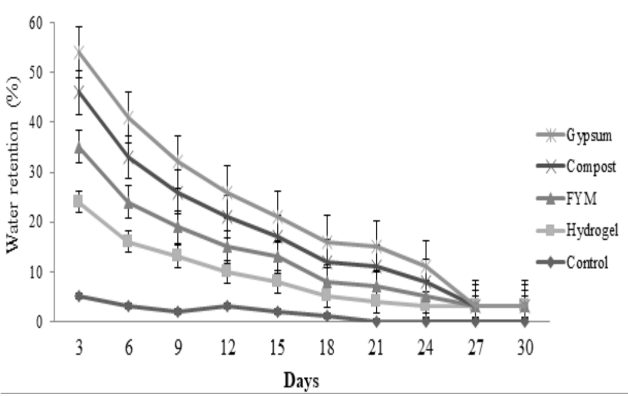

Figure 5: Impact of soil amendments on soil water retention

After the application of hydrogels, the water is absorbed by osmosis and interacts with hydrogen atoms as positive ions leaving negative ions along the length of the polymer chain. This yielded several negative charges in its length which repel each other to unwind the polymer chain. The water molecules bind them with hydrogen bonding (Vicky, 2007). The application of hydrogels may serve as a slow-release water reservoir in soil that may retain soil water for extended time as these are capable of absorbing water several hundred times of their weight (Monnig *et al.*, 2005).

Conclusion

The data obtained in this experiment showed that the application of soil conditioners including hydrogels possesses better water-retaining capacity. The addition of the hydrogel has improved water retention (73%) and enhanced wheat yield (42%). Additionally, soil conditioners have enhanced soil fertility. Therefore, it can be predicted that the application of hydrogel could be successful in maintaining stable plant growth under water stress conditions. But the variability in the performance of hydrogels warrants further investigations for the recommendations of the specific hydrogel according to soil types.

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