Effects of Hydrogel on Physical and Chemical Properties of Soil

Abstract

This experiment was performed at the Rajiv Gandhi South Campus, Barkachha (BHU) Mirzapur, as a pot culture study, from November 2018 to March 2019–20. This experiment is a completely randomised design, taking three replications with six treatments, i.e., T_1: Control, T_2: 5 g kg^{-1} Hydrogel, T_3: 10 g kg^{-1} Hydrogel, T4: 15 g kg^{-1} Hydrogel, T5: 20 g kg^{-1} Hydrogel, and T_6: 25 g kg^{-1} Hydrogel. The soil was incubated with different doses of hydrogel for 120 days. The samples were collected after incubation, processed in a laboratory, and analysed for physical and chemical properties of soil. The results demonstrated that the use of hydrogel had a significant impact on the various soil properties, particularly the water holding capacity and bulk density of the soil. Other soil properties that were significantly influenced were particle density, porosity, electrical conductivity, soil available nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur. However, the application of hydrogel did not influence the pH of soil or the organic carbon content of soil. The application of hydrogel at a rate of 25 g kg1 showed the highest values of available N, P, K, and S content in soil as well as the water holding capacity. In some soil properties, the treatment containing 25 g kg^{-1} hydrogel was found to be statistically equivalent to that containing 20 g kg^{-1} hydrogel.

Key word: *Hydrogel, Polymer, Organic Carbon, Available nitrogen etc.*

1. Introduction

India is an agricultural country where, in most fields, rain-fed agriculture is followed. India is first among the rain-fed countries of the world in terms of area. In terms of yield, it is the lowest, with around 1 tonne ha1.Though the maximum cultivated area is under rain-fed conditions, More than 45% of cereals, 66% of oilseeds, and 75% of pulses are grown under rainfed conditions (Kalhapure et al. 2016).

The stress crunch of inefficient use of rainwater and irrigation water by rain-fed crops is a countable problem in arid and semiarid regions. The water-holding soil conditioners are mostly helpful where there is reduced water availability. It is well known that hydrogel can hold large amounts of water and help in checking nutrient losses, which are free as and when expected by the plant, and it is possible that plant growth could be improved under scarce water and nutrient supply (Gehring and Lewis, 1980). Application of water-saving hydrogel (SAP), i.e., super absorbent polymer, into the soil could be an effective way to increase nutrient use efficiency and water use efficiency in crops.

Water hydrogels absorb water and promote crop growth, resulting in increased land productivity. The use of high-yielding varieties, irrigation, and fertiliser application in conjunction with hydrogels could result in significant production responses (Kukal et al. 2014).Superabsorbent polymers, also called slush powder, can absorb and retain a very large quantity of liquid relative to their own mass. Its ability to absorb and retain water depends on the aqueous solution's ionic concentration. In distilled or deionized water, a hydrogel may absorb about 300 times its weight, which is about 30–60 times its own volume, and it can become liquid up to 99.9%. But when it is put into a 0.9% saline solution, its absorption capacity drops to approximately 50 times its weight (Horie et al*., 2004*).

Water scarcity has become a global concern because of increasing demands from industries, agriculture, urban inhabitation, and an increasing population. These issues are exacerbated further by ever-changing climatic conditions.The paucity of water and desertification in many arid and semiarid regions of India are increasing; this problem may be solved by the use of hydrogels (Vundavallia & Ramesh, 2015).

Water stress is a major factor limiting crop growth and productivity, as well as other environmental factors. These hydrophilic polymers are more effective in reclamation and restoration projects where post-planting irrigation facilities are limited, as well as in plant protection. Indian soils are poor in terms of soil depth, fertility, and organic carbon content in surface soils. The availability of soil moisture in off-season or non-rainy months is a major concern. Although the soils are productive, we are unable to grow food all year due to a lack of soil moisture. Application of hydrogel technology could supplement the crop's water availability.

2. MATERIAL AND METHOD

2.1 Experimental area and pot experiment

From November 2018 to March 2019-20, this experiment was carried out as a pot culture study, followed by laboratory analysis of the collected soil samples at Rajiv Gandhi South Campus, Barkachha, and Banaras Hindu University, Mirzapur.The district stretches out between the central Gangetic plain basin in the north and the Vindhyan range in the south. The southern bumpy parcels of eastern Uttar Pradesh, covering Mirzapur, structure an unmistakable geological district called Vindhyachal.

The pot experiment was performed to see the effects of hydrogel on soil nutrients released in the rabi season, and different doses of hydrogel were applied in pots along with soil and incubated for four months. However, the bulk of the soil was obtained from the agricultural farm of RGSC, Barkachha, Banaras Hindu University, and Mirzapur.

2.2 Experimental Details

The experimental design for data analysis was a CRBD (completely randomised design) with 3 replications and 6 treatments; for the pot experiment, each treatment required 10 grammes of soil; the following treatments are denoted as T1 Control (no application), T2 (5 g kg-1 hydrogel), T3 (10 g kg-1 hydrogel), T4 (15 g kg-1 hydrogel), T5 (20 g kg-1 hydrogel), and T6 (25 g kg-1 hydrogel).

2.3 Analyses of soil samples

The soil samples are analysed for different soil physical and chemical properties available in soil, i.e., bulk density and particle density, water holding capacity, porosity, soil pH, and EC, as well as organic carbon, available nitrogen, phosphorus, and potassium, with micronutrients sulphur, calcium, and magnesium, through the following scientifically applicable formula.

2.4 Bulk density and particle density:

The bulk density was analyzed by

Bulk density (g/cm^{-3}) = Weight of soil (y - x)/$_{\text{Volume of solid and pores (z)}}$

Whereas,

Weight of pycnometer = x (g), Weight of pycnometer + soil = y (g), Volume of pycnometer = z (mL)

The particle density was calculated as per the procedure outlined by Black *et al.*, 1965

2.5 Water holding capacity

$$\text{Water holding capacity (\%)} = \frac{\text{Weightof waterheldby a soil}}{\text{Weightof ovendrysoil}} \times 100$$

2.6 Porosity

$$\text{Porosity (\%)} = (1 - \text{Bulk density / Particle density}) \times 100$$

2.7 Soil pH and EC

The pH of soil was measured by pH meter (Chopra and Kanwar, 1982). The electrode of the conductivity meter was inserted in clear part of the suspension and the EC(Electrical conductivity) of the soil was measured and presented in unit dS m^{-1} (Sparks, 1996).

2.8 Organic Carbon

Organic carbon content in soil was estimated by chromic acid wet digestion method (Walkley and Black, 1934)

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$$\%\ \text{Organic 'C' in soil} = \frac{\text{(B-S) x 0.003 x 10 x 1 x 100}}{\text{B x wt. of soil}}$$

Where,

B = Volume of 0.5 *N* FAS consumed for blank titration

S = Volume of 0.5 *N* FAS consumed for sample titration

2.9 Available Nitrogen, phosphorus and potassium

The available nitrogen content in the soil was estimated as per the procedure outlined by Subbiah and Asija (1956). The available phosphorus content of soil was determined by Olsen's method (Olsen *et al*., 1954). The extractant neutral ammonium acetate was used to estimate the available potassium content in the incubated soil samples (Jackson et al., 1973) are:-

$$\text{Available N (kg ha}^{-1}\text{)} = \frac{(S-V) \times 0.02 \times 14 \times 10^6 \times 2.24}{1000 \times 5}$$

Whereas, S -Sample titration reading V -Blank titration reading

Available P (kg ha^{-1}) = (Absorbance x dilution factor x 2.24)/ Slope of the standard curve

Available K (kg ha^{-1}) = C x dilution factor x 2.24

2.10 Available calcium and magnesium

The available Ca^{+2} and Mg^{+2} was determined by complex metric titration method (Cheng and Bray 1951).

Ca or Ca + Mg ($mgkg^{-1}$)= (R x Normality of EDTA x1000) / Aliquot (mL)

Where, R = volume (mL) of standard EDTA used in titration

2.11 Available Sulphur

Available sulphur content in soil was determined by Turbidity method (Chesin and Yein, 1951).

Available S (ppm) in soil = $\frac{\text{absorbance}}{\text{Slope of std curve}}$ x dilution factor

3. RESULT AND DISCUSSION

The bulk density of soil at different levels of hydrogel ranged from 1.22 to 1.38 mg/m3. The maximum bulk density (1.38 Mg/m3) was recorded in soils under control. While applying 25 g/kg of hydrogel resulted in a minimum bulk density of 1.22 Mg/m3, From the data, it is also clear that the bulk density decreased with the increased application of hydrogel. The bulk density obtained in treatments T5 (20 g kg1) and T6 (25 g kg1) was statistically equivalent to that obtained in previous studies. The bulk density decreased in the present study with increasing levels of hydrogel; this might be attributed to the storage of water due to hydrogel application and the replacement of mineral matter with organic copolymer. A decrease in bulk density was also reported by Shiva Kumar *et al*. (2018). The particle density of soil as affected by different levels of hydrogel ranged from 2.52 to 2.64 mg/m3. The maximum particle density (2.64 mg/m3) was recorded in soils under control. However, the application of 25 g of hydrogel per kilogram resulted in the lowest particle density (2.52 mg/m3). From the data it is also clear that the particle density decreased with the increased application of hydrogel it was presented by table 1.

The maximum water holding capacity (257%) was found with the application of 25 g/kg of hydrogel, as compared to 5 g/kg (243.8%), 10 g/kg (197.4%), 15 g/kg (218.4%), and 20 g/kg (243.8%) of hydrogel. The data analysis clearly showed that increasing the levels of hydrogel significantly increased the water holding capacity. The results of the present investigation strongly corroborate the work done by Akhter *et al*. (2004). An increase in the water-holding capacity of soil due to the application of hydrogel was also reported by Pattanaik*et al*. (2015) and Montesano *et al*. (2015). Analyzed data clearly revealed that the soil porosity was increased significantly and linearly with the increasing levels of hydrogel; Shiva Kumar *et al*. (2012) also reported higher porosity with higher doses of hydrogel in the soil, as shown in Table 1.

The data clearly revealed that the maximum soil pH (6.78) was found with the application of 25 g/kg hydrogel as compared to 5 g/kg (6.52), 10 g/kg (6.65), 15 g/kg (6.69), and 20 g/kg (6.75) hydrogel. The data analysis clearly showed that increasing the levels of hydrogel and soil did not significantly increase soil pH. With increasing levels of hydrogel, electrical conductivity increased significantly. The basic cations are mostly dissolved in minerals and organic matter substances that might increase the soil's electrical conductivity, as shown in Table 1.

The application of 25 g kg-1 Hydrogel yielded the highest organic carbon (0.51%) when compared to 5 g kg^{-1} (0.36%), 10 g kg^{-1} (0.40%), 15 g kg^{-1} (0.45%), and 20 g kg-1 (0.51%) Hydrogel. The analysed data clearly demonstrated that soil organic carbon increased with increasing levels of hydrogel as possible; similar data was discovered by Agaba et al. (2010) and is shown in Table 2.

Available nitrogen (kg ha^{-1}) in soil was increased with increasing levels of hydrogel among different treatments. The maximum available nitrogen (152.7 kg ha^{-1}) was recorded with the application of 25 g/kg, which was found to be statistically at par with 142.3 kg ha^{-1} with the application of 20 g/kg Hydrogel. This result analogues findings in Hydrogel application to soil, which minimises macro- and micronutrients from washing out to groundwater tables and increases the water consumption efficiency; they may also reduce the quantity of nutrient fertilization since the nutrient leaching in soil is limited by decreasing the runoff. The nutrients are released through soil nitrification (El-Hady, 1981). The application of 25 g of hydrogel per kg of weight resulted in the highest available phosphorus content (10.92 kg ha-1) when compared to 5 g per kg of weight (8.23 kg ha^{-1}), 10 g per kg of weight (9.09 kg ha^{-1}), 15 g per kg of weight (10.3 kg ha^{-1}) and 20 g per kg of weight (10.7 kg ha^{-1}). Hydrogel application provides favourable conditions for its solubilization and release from complex compounds into soil solutions. Increasing the level of hydrogel in soil increases the available potassium content (kg ha^{-1}) among different treatments. The maximum available potassium content (179.2 kg ha^{-1}) was found to be statistically equal to the maximum available potassium content (160.5 kg ha^{-1}) with the application of 20 g of hydrogel per kg of soil. Hydrogel provides favorable conditions for the release of potassium from interlayer spaces as well as its exchange with clay colloids and increases its availability in soil. As there was no crop taken in the present investigation, there was no uptake of nutrient elements (Palanivelu *et al*., 2022). As a result, whatever nutrients were released remained in the soil solution due to the moist condition of the soil. This might be a probable reason for the release of potassium from the soil and its increased availability in soil because it was exposed in Table 2.

Soil is improved with increasing levels of hydrogel among different treatments. The maximum available calcium content (11.8 mg kg^{-1}) was recorded with the application of 25 g kg1. Hydrogel was followed by 10.8 mg kg1 with a 20 g kg^{-1} application. Several researchers have reported that hydrogel-treated plants generally require 20% less fertiliser than untreated plants (Repac *et al*., 2013; Chen *et al.,* 2012). Available magnesium content (mg kg1) in soil increases with increasing levels of hydrogel among different treatments. The maximum available magnesium content (10.7 mg kg^{-1}) was recorded with the application of 25 g kg^{-1}. Hydrogel Some research indicates that the banding of polymer in the furrow could reduce the total nutrient requirements for a particular crop, as the superabsorbent polymers tend to increase the reserve pool of nutrients in the rhizosphere soil and increase the uptake efficiency of the nutrient elements in the plant (Orzolek, 1991 Sahmat et al., 2022). Available Sulfur content (mg kg^{-1}) in soil increases with increasing levels of hydrogel among different treatments. The maximum available sulphur content (10.7 mg kg^{-1}) was recorded with the application of 25 g kg^{-1}. Hydrogel was also reported. Hydrogel forms a flexible envelope in soil; it mimics the effects of mucilages, which are naturally exuded by the roots of plants in order to maintain water and ion exchange processes between the rhizosphere and the root system. Hydrogel application influences the growth of soil microorganisms and therefore may increase the availability of various organic and inorganic nutrients in soil (Landis and Haase, 2012).

CONCLUSION

Hydrogel, or superabsorbent polymer, is a very effective technology used in dryland and rainfed agriculture. It can not only hold the water but also provide it slowly and steadily. They help to increase the efficiency of irrigation, water productivity, and water availability. The maximum bulk density (1.38 Mg/m3) was recorded in soils under control. Maximum water holding capacity (257%) was found with the application of 25 g kg^{-1} hydrogel, and soil porosity increased linearly with the increasing hydrogel levels. The maximum soil pH (6.78) was found with the application of 25 g kg^{-1} Hydrogel. Electrical conductivity was significantly increased. Available nitrogen (kg ha^{-1}) in soil was increased with increasing levels of hydrogel among different treatments.

The maximum available phosphorus content (10.92 kg ha^{-1}) was obtained by using 25 g of hydrogel per kilogramme as opposed to 5 g of hydrogel per kilogram. Hydrogel facilitates the release of potassium from interlayer spaces as well as its exchange with clay colloids, increasing its availability in soil. The maximum available potassium content (179.2 kg ha^{-1}) was recorded with the application of 25 g kg^{-1} Hydrogel. The maximum available calcium content (11.8 mg kg^{-1}) was recorded with the application of 25 g of hydrogel, followed by magnesium (10.7 mg kg^{-1}). With increasing levels of hydrogel among different treatments, the maximum available sulphate content in soil increases. Hydrogel forms a flexible envelope in soil; it mimics the effects of mucilages, which are naturally exuded by the roots of plants. It may increase the availability of various organic and inorganic nutrients in the soil. Available sulphur content (mg kg^{-1}) in soil increases with increasing levels of hydrogel.

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Table 1 Effect of Hydrogel on soil Bulk Density, Particle Density, water holding capacity, Porosity, pH and electrical conductivity (EC)

Treatments	Bulk Density (Mgm^{-3})	Particle Density (Mgm^{-3})	WHC (%)	Porosity (%)	pH (1:2.5 Soil - Water)	EC (dS m^{-1})
T_1 - Control	1.38	2.64	38.3	47.7	6.47	0.065
T_2–5 g kg^{-1} Hydrogel	1.37	2.62	167.9	47.8	6.52	0.069
T_3 - 10 g kg^{-1} Hydrogel	1.35	2.60	197.4	48.0	6.65	0.087
T_4 - 15 g kg^{-1} Hydrogel	1.28	2.57	218.4	50.1	6.69	0.097
T_5 - 20 g kg^{-1} Hydrogel	1.24	2.55	243.8	51.4	6.75	0.099

T_6 - 25 g kg^{-1} Hydrogel	1.22	2.52	257.0	51.7	6.78	0.109
SEm±	0.007	0.008	1.664	0.35	0.040	0.004
CD (P=0.05)	0.022	0.024	5.184	1.08	NS	0.012

Table 2 Effect of Hydrogel on soil Organic carbon and available nitrogen, phosphorus, potassium, calcium, magnesiumand sulphurcontent in soil

Treatments	Organic carbon (%)	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})
T_1 - Control	0.33	113.7	6.07	93.3	8.1	8.5	2.20
T_2 - 5 g kg^{-1} Hydrogel	0.36	127.5	8.23	112.0	8.7	9.1	2.46
T_3 - 10 g kg^{-1} Hydrogel	0.40	135.8	9.09	123.2	9.7	9.6	2.59
T_4 - 15 g kg^{-1} Hydrogel	0.45	137.7	10.3	134.4	10.4	9.8	2.73
T_5 - 20 g kg^{-1} Hydrogel	0.46	142.3	10.7	160.5	10.8	10.5	3.92
T_6 - 25 g kg^{-1} Hydrogel	0.51	152.7	10.9	179.2	11.8	10.7	4.53
SEm±	0.041	0.855	0.51	0.871	0.175	0.420	0.377
CD (P=0.05)	NS	2.79	1.59	2.715	0.545	1.309	1.174