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Hydrogel as a Soil Amendment for Enhancing Tomato Growth and Soil Health in Sandy Soils of Bundelkhand, Uttar Pradesh, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A pot experiment was conducted at Organic Research Farm, Karaguanji, Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Bundelkhand University, Jhansi, (U.P.), during *Kharif* Season 2024-25. This study aims to the effect of hydrogel, deficit irrigation and course sandy soil type on water holding capacity, soil physic-chemical properties and

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yield attributes and yields of Tomato with six treatments and four replications. The results clearly revealed that application of hydrogel significantly improved soil properties such as WHC, available nitrogen, phosphorous and potassium. Treatments having RDF+1.0% hydrogel (T_5) having highest porosity and lowest bulk density and particle density value than other treatments. Consequently, a significantly higher number of fruits per plant, fruit diameter, average fruit weight and yield found in RDF + 1.0 hydrogel (w/w) (T_5) treatment. Therefore, it can be summarized that addition of RDF + 1.0 hydrogel (w/w) (T_5) recommendation significantly improved soils physical and chemical. This leads to a significant increase in tomato production. Results finding confirms that the application of hydrogels might be suggested to improve soil water holding capacity and enhance water use efficiency arid and semi arid conditions.

Keywords: Hydrogel; soil properties; water holding capacity; crop yield and soil density.

1. INTRODUCTION

"Tomato (*Solanum lycopersicum* L.) is a widely grown and versatile vegetable throughout the world for its taste, colour, high nutritive value, and diversified use. Tomato is one of the most important and most widely consumed vegetable crops in the world. Tomato is a member of the Solanaceae family which includes more than 3000 species in around 90 genera" (Morris and Taylor, 2017). "With 1,245 officially recognized species found across all temperate and tropical continents, the genus Solanum L. is among the largest and most economically significant genera globally" (Hilgenhof et al., 2023). "These species are notable for their morphological and ecological diversity. Commercially produced Solanaceous crops include potato, tomato, chili, and brinjal. Lesserknown varieties consist of pepino, lulo (or naranjilla), tree tomato (or tamarillo), scarlet brinjal, gboma brinjal, and bush tomato. The cherry tomato, known scientifically as S. lycopersicum var. cerasiforme, is believed to be the most likely ancestor of the cultivated tomato. The basic chromosomal number for species in the genus Solanum is x=12; however, many of these species also exhibit polyploidy, with chromosome counts of 2n=24, 36, and 48. Since tomatoes are true diploids, they have 2n=2x=24 chromosomes" (Kumar and Peter, 2020).

"Hydrogels (Synthetic hydrophilic polymers) are specific class of gels formed by chemical stabilization of hydrophilic polymers in a three-dimensional network. The synthetic polymers are crystalline in shape and are available under different trade names, namely the Super Absorbent, Raindrops, Terracottem, Aquasorb, Zeba gel, Pusa Hydrogel etc. In pure water, the hydrogel exhibited a minimum of 350 times swelling potential, often exceeding 500 times its weight. Remarkably, rise in temperature up to 500^{o}C resulted in increased swelling ratio without any unfavorable impact on the structure of the polymer matrix. It improves the productivity of crops per unit of water and available nutrient, particularly under moisture stress conditions. It improves the physical properties of a soil like bulk density, water holding capacity, porosity etc and plant parameters viz., seed germination, seedling emergence rate, root growth and enable plants to survive under longer periods of moisture stress" (Ekebafe et al., 2011). The irrigation demand can also be reduced from 100 to 85 per cent and thus enhances crop yield and water use efficiency. Thus hydrogel enhance the plant establishment effectively through good supply of soil moisture (Muhammad et al., 2015). "The hydrophilic polymers can absorb water, as much as several hundred times their weight" (Wallace and Wallace, 1986)

Soil conditioning with hydrogel in the agricultural field could be a unique approach that acts as a miniature reservoir for water storage (Dabhi et al., 2013). Recent research investigations have observed that problems associated with conventional micro irrigation and catalytic influence can be mitigated by treating the soil with super absorbent polymer.

2. MATERIALS AND METHODS

The field experiment was conducted at organic research Farm, Karaguanji, Department of soil science and agricultural chemistry, Institute of Agricultural Sciences, Bundelkhand University, Jhansi, U.P., situated at Bundelkhand region of Uttar Pradesh at 25°31'07.1" N latitude and longitude of 78°33'47.4 E with 284 meters above from mean sea level (MSL). According to NARP, Bundelkhand falls in Agro climatic zone VI (Bundelkhand Zone of UP). The soils of the district are characterized by their varying depth, topographic situations and colors. The two main soil groups are red and black that generates four soil series locally known as rakar, parwa, kabar and mar. The soil texture varies from rocky, gravely, sandy, sandy loam to clay loam and having gentle to steep (0.5 to 10 %) slope with low to medium WHC content and very low to high water holding capacity. Farming situations and cropping patterns vary as per soil type, water, vegetation and livestock availability.

The experiment consisted 6 treatments; Control (T_0), STCR (T_1), RDF + 0.25 hydrogel (W/W) (T_2), RDF + 0.50 hydrogel (W/W) (T_3), RDF + 0.75 hydrogel (W/W) (T_4) and RDF + 1.0 hydrogel (W/W) (T_5). The experiment was laid out in complete randomized design with four replications.

The effects of treatments were evaluated in terms of growth, yield attributes, yield, nutrient content as well as uptake, quality, and soil fertility status after harvest of crop. The methods and procedure adopted are height of plant recorded from the base just above the soil surface to growing point of the plant with help of meter scale. The height was recorded at 30, 60 DAT and harvesting. The average plant height was calculated and expressed in centimeters. The total number of branches in each plant was counted at 60 days after transplanting (DAT) and mean value for each treatment was determined. The total number of leaves in each plant was counted at 60 and 120 days after transplanting (DAT) then mean value for each treatment was determined. Diameter of plant recorded from the base just above the soil surface of the plant and indicated as cm. The total number of fruits per plant counted in all the pickings. Ten fruits were randomly selected from each pot from previously selected plants and weight of fruit was counted and means value for fruit weight was calculated as average fruit weight.Five fruits was selected randomly from tagged plants and there diameter was measured in cm. Mean value of diameter was expressed as fruit diameter. The weight of the tomato fruits were harvested treatment wise from each net pot and from each replication was recorded. The total yield per pot was estimated based on the fruit yield per pot from each harvest and was expressed as kg per pot.

To find out the fertility status of soil, the soil sample was taken from each pot after harvest of tomato. The samples were air dried, powdered and passed through 2 mm plastic sieve to avoid metallic contamination. The soil sample was analyzed for available nitrogen, phosphorus and potassium content.

3. RESULTS AND DISCUSSION

Data presented in Table 1 showed that WHC status of the soil at harvest stage of the crop increased significantly with increasing levels of hydrogel. “The significantly maximum WHC (42.92 per cent) was observed under T_5 (RDF + 1.0 hydrogel) and the minimum (39.41 per cent) under control (T_0). Water holding capacity was higher with hydrogel applied at higher rate due to reduction in evaporation of absorbed water from the soil” (Akther et al., 2004).

It is evident from data presented in Table 1 found that the application of hydrogel before transplanting of tomato significant increased the available nitrogen in soil. The application of treatment T_5 (RDF + 1.0 hydrogel) was observed higher available nitrogen in soil as compared to control. The maximum available nitrogen was recorded in treatment T_5 (175.45 kg/ha) that is RDF + 1.0 hydrogel, which was at par with T_4 (RDF + 0.75 hydrogel). “Application of RDF increases the availability of available nitrogen in soil because it’s significantly increase the tomato root biomass which increase the mineralization of plant nutrients in soil. Availability of macro nutrients were higher in treatment where hydrogel application was done and also due to higher nutrient holding of soil. The availability of nitrogen showed increasing trend. Hydrogel higher biomass production with higher nutrient uptake resulting in depleting nutrients in soil” were reported by Shivakumar et al. (2018) and Seyed et al. (2010).

The data given in Table 1 showed that application of hydrogel significantly increased the available phosphorus at harvest. Application of T_5 (RDF + 1.0 hydrogel) recorded significantly higher available phosphorus that was 12.74 kg/ha at harvest over control. Availability of macro nutrients were higher in treatment where hydrogel application was done due to higher availability of water microbial population increase and cause higher mineralization of phosphorus in soil and increase availability of phosphorus. This may be attributed to higher uptake of nutrients that corresponds to higher biomass production and its further translocation to various plant parts including fruit, besides, being subjected to other losses.

It is evident from data presented in table 1 found that the application of hydrogel before transplanting of tomato significant increased the available potasium in soil. The application of treatment T_5 (RDF + 1.0 hydrogel) was observed higher available potassium in soil as compared to control. The maximum available potassium was recorded in treatment T_5 (184.21 kg/ha) that is RDF + 1.0 hydrogel, which was at par with T_4 (RDF + 0.75 hydrogel). "Application of RDF increases the availability of available potassium in soil because its significantly increase the tomato root biomass which increase the mineralization of plant nutrients in soil. Availability of macro nutrients were higher in treatment where hydrogel application was done and also due to higher nutrient holding of soil. The availability of potassium showed increasing trend. Hydrogel higher biomass production with higher nutrient uptake resulting in increasing nutrients in soil" were reported by Shivakumar et al. (2018) and Seyed et al. (2010).

The critical appraisal of data presented in Table 1 revealed that the effect of hydrogel on EC of the soil at harvest stage of tomato was found non-significant. Soil EC slightly increased due to hydrogel might increases the water retention capacity and also increases the nutrient holding capacity of soil. It helps to reduce the leaching loss of cations from the top soil leading to accumulation of ions *viz*. Ca^{2+}, Mg^{2+}, K^+, Na^+ etc ions in the soil. Unchanged in organic carbon mainly due to added hydrogel is very less to increase the organic carbon in soil. So accumulation of these ions in soil increases the EC of soil. El-Hady et al. (2006) reported that application of hydrogel increase the EC.

The critical appraisal of data presented in Table 1 revealed that the effect of hydrogel on bulk density, particle density and porosity of the soil at harvest stage of tomato was found nonsignificant. Linear decrease in bulk density may be due to hydrogel occupy the large pore space, increases the porosity and volume of the soil. Hydrogel particle absorbs water and forms larger in size in the soil matrix. The soil particles are displaced and rearranged around the swollen particles of the hydrogel might increase soil volume and hence the ratio of the dry mass of the soil to its volume decreases. This result is analogous with the conclusions of El-Hady et al. (2006) and Gales et al. (2016).

The critical appraisal of data presented in Table 2 revealed that the levels of hydrogel influenced the plant height significantly at different stages of crop growth (Table 3). At 30, 60 days after transplanting (DAT) and harvesting, treatment T_5 (RDF + 1.0 hydrogel) recorded significantly higher plant height 33.72, 78.71 and 117.56 cm respectively, which was at par with treatment T_4. Lower plant height was observed with control (26.55, 60.50 and 91.50 cm respectively). The levels of hydrogel have enhanced the growth attributes of tomato crop. Application of RDF + 1.0 hydrogel to tomato crop performed better growth attributes with more number of branches, plant height and stem diameter as compared to control. Consistent availability of soil moisture in soil higher due to higher rate of hydrogel had influenced better nutrient transformation and uptake by the plant (Yazdani et al., 2007). This had resulted in better physiological activity and hence better growth attributes were observed in RDF + 1.0 hydrogel as compared to remaining treatment.

The application of treatment T_5 (RDF + 1.0 hydrogel) recorded higher plant height due to higher water and nutrient holding capacity of soil leads might improved nutrient availability in the vicinity of the *rhizosphere* coupled with better root activity. The higher rate of nutrient absorption, translocation and production of more dry matter and fruit yield leads to increased uptake of applied nutrient (Karimi et al., 2008). Hydrogel application enhances continuous availability of soil moisture that might helped in

Table 1. Effect of hydrogel on soil properties after harvesting of tomato

Treatments	WHC (%)	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	EC (dSm^{-1})	Density (Mg/M^3)	
						Bulk	Particle
T_0	39.41	126.75	8.70	125.75	0.54	1.43	2.66
T_1	40.34	143.56	10.43	150.74	0.55	1.42	2.65
T_2	41.53	151.03	10.97	158.60	0.56	1.41	2.65
T_3	41.46	158.19	11.48	166.12	0.58	1.41	2.65
T_4	41.65	163.59	11.87	171.79	0.601	1.40	2.64
T_5	42.92	175.45	12.74	184.21	0.613	1.40	2.64
SEm (±)	0.36	4.96	0.49	6.97	0.05	0.04	0.001
CD(*p*=0.05)	1.08	14.74	1.45	20.72	NS	NS	NS

solubilizing the plant nutrients near the root zone with minimum nutrient leaching, which favoured better absorption of the plant nutrients by the crop. Similar observations were noticed by, Hamid et al. (2013), Rakshithkumar et al. (2018) and Tyagi et al. (2015).

The critical appraisal of data presented in Table 3 revealed that the levels of hydrogel influenced the number of branches per plant significantly at harvesting of tomato. Treatment T_5 (RDF + 1.0 hydrogel) recorded significantly higher number of branches per plant 14.32. Lower number of branches per plant was observed with control (10.83). The levels of hydrogel have enhanced the growth attributes of tomato crop. Application of RDF + 1.0 hydrogel to tomato crop performed better growth attributes with more number of branches as compared to control. Consistent availability of soil moisture in soil higher due to higher rate of hydrogel had influenced better nutrient transformation and uptake by the plant (Yazdani et al., 2007). This had resulted in better physiological activity and hence better growth attributes were observed in RDF + 1.0 hydrogel as compared to remaining treatment.

The data given in Table 3 showed that application of hydrogel significantly increased the stem diameter of tomato at harvest. Application of T_5 (RDF + 1.0 hydrogel) recorded significantly higher stem diameter that was 1.12 cm at harvest over control. Application of RDF + 1.0 hydrogel recorded maximum diameter of stem. The application of hydrogel had facilitated to hold abundant amounts of soil moisture and subsequent supply to the plant throughout the cropping period ensured consistent soil moisture supply (Silberbush et al., 1993). Also, the application of hydrogel had increased adsorption of nutrient elements and thus improved nutrient availability to the crop. The enhanced nutrient and soil moisture availability had resulted in better growth attributes. Increased growth parameter due to hydrogel retains absorbed water and nutrients for longer period and supplies it throughout the crop period compared to control. These results were in line with Akhther et al. (2004) in chickpea and Anupama et al. (2005) in chrysanthemum.

The critical appraisal of data presented in Table 2 revealed that the levels of hydrogel influenced the plant height significantly at different stages of crop growth (Tables 3). At 60 days after transplanting (DAT) and harvesting, treatment T_5 (RDF + 1.0 hydrogel) recorded significantly number of leaves 79.39 and 150.08 respectively. Lower plant height was observed with control (60.0 and 115.5 respectively). The levels of hydrogel have enhanced the growth attributes of tomato crop. Application of RDF + 1.0 hydrogel to tomato crop performed better growth attributes with more number of leaves at 60 DAS and harvesting as compared to control. Consistent availability of soil moisture in soil higher due to higher rate of hydrogel had influenced better nutrient transformation and uptake by the plant (Yazdani et al., 2007). This had resulted in better physiological activity and hence better growth attributes were observed in RDF + 1.0 hydrogel as compared to remaining treatment.

Application of RDF + 1.0 hydrogel recorded higher number of leaves. The application of hydrogel had facilitated to hold abundant amounts of soil moisture (300-400 times the weight of hydrogel) and subsequent supply to the plant throughout the cropping period ensured consistent soil moisture supply (Silberbush et al., 1993). Also, the application of hydrogel had increased adsorption of nutrient elements and thus improved nutrient availability to the crop.

Table 2. Effect of Hydrogel on soil porosity, plant height and no. of leaves of tomato

Treatments	Porosity (%)	Plant height (cm) at			No. of leaves	
		30 DAT	60 DAT	At harvesting	60 DAT	At harvesting
T_0	46.27	26.55	60.50	91.50	60.00	115.50
T_1	46.51	29.29	64.53	98.45	65.13	125.39
T_2	46.66	30.95	68.18	104.01	68.80	132.45
T_3	46.81	32.53	71.68	109.32	72.29	139.16
T_4	46.91	33.71	74.28	113.29	74.93	144.24
T_5	47.17	35.72	78.71	117.56	79.39	150.08
SEm (±)	0.04	0.75	1.63	1.73	0.59	1.6
CD(p=0.05)	NS	2.22	4.84	5.15	1.77	4.75

Table 3. Effect of Hydrogel on No. of branches per plant, Stem diameter, Average fruit weight, No. of fruits and Yield pot per plant, and Fruit diameter

Treatments	No. of branches plant^{-1}	Stem diameter (cm)	Average fruit weight (g)	No. of fruits plant^{-1}	Yield pot-1 (kg)	Fruit diameter (cm)
T_0	10.83	0.85	61.25	26.00	2.43	5.06
T_1	11.76	0.92	66.45	29.33	2.88	5.14
T_2	12.42	0.97	70.21	31.25	3.03	5.30
T_3	13.04	1.02	73.80	34.25	3.18	5.46
T_4	13.52	1.06	76.48	38.50	3.28	5.64
T_5	14.32	1.12	81.04	40.25	3.52	5.82
SEm (±)	0.23	0.05	2.4	0.76	0.07	0.07
CD(p=0.05)	0.67	0.15	7.12	2.25	0.22	0.22

The enhanced nutrient and soil moisture availability had resulted in better growth attributes. Increased growth parameter due to hydrogel retains absorbed water and nutrients for longer period and supplies it throughout the crop period compared to control. These results were in line with Akhther et al. (2004) in chickpea and Anupama et al. (2005) in chrysanthemum.

The critical appraisal of data presented in Table 3 revealed that the levels of hydrogel influenced the average fruit weight (g) significantly at harvesting of tomato. Treatment T_5 (RDF + 1.0 hydrogel) recorded significantly higher average fruit weight (g) (81.04 g). Lower average fruit weight (g) was observed with control (61.25 g). Average fruit weight (g) increased with increased levels of hydrogel. RDF + 1.0 hydrogel significantly improved the fruit weight due to higher availability of soil moisture and nutrients in soil, which resulted in increased number of branches as well as biomass. Under limited water condition hydrogel was able to retain higher moisture in the crop root zone and help the plant to sustain against drought condition. Further, it also helps nutrients uptake at proper ratio by increasing nutrient holding capacity and their subsequent release. Similar findings were reported by Meena et al. (2011) in tomato crop.

It is evident from data presented in Table 3 found that the application of hydrogel before transplanting of tomato significant increased the number of fruits plant^{-1}. The application of treatment T_5 (RDF + 1.0 hydrogel) was observed higher number of fruits plant^{-1} as compared to control. The maximum number of fruits plant^{-1} was recorded in treatment T_5 (40.25) that is RDF + 1.0 hydrogel, which was at par with T_4 (RDF + 0.75 hydrogel). Number of fruits per plant increased with increased levels of hydrogel. RDF + 1.0 hydrogel significantly improved due to increased availability of N, P and K which resulted in increased number of leaves per plant and number of branches as well as biomass. Under limited water condition hydrogel was able to retain higher moisture in the crop root zone and help the plant to sustain against drought condition.

Similar findings were reported by Hamid et al. (2013) in ground nut, Meena et al. (2011) in tomato crop.

The critical appraisal of data presented in Table 3 revealed that the levels of hydrogel influenced the fruit yield significantly. Treatment T_5 (RDF + 1.0 hydrogel) recorded significantly higher yield per pot 3.52 kg. Lower yield was observed with control (2.43 kg). Application of RDF with different levels of hydrogel recorded significant increase in yield of tomato (Table 3). Inorganic fertilizers rapidly supply macro nutrients to the crop so growth and yield attributing characters are significantly very high. The significant increase in fruit yield with application of 1.0 % hydrogel and RDF might be due to their favourable influence on maintaining balanced sourcesink relationship which clearly evident from remarkable improvement in dry matter production, growth and yield attributes *viz*., number of fruits plant^{-1}, fruit yield per plant and fruit weight, which ultimately increased fruit yield. The increase in haulm yield with the application of RDF + 1.0% hydrogel could be attributed to its direct influence on dry matter accumulation of each and every vegetative part and indirectly through the improved morphological growth parameters. These results are in closed agreement with findings of Otitoloju (2014), Zohre et al. (2013) and Hamid et al. (2013).

It is evident from data presented in Table 3 found that the application of hydrogel before transplanting of tomato significant increased the fruit diameter (cm). The application of treatment T_5 (RDF + 1.0 hydrogel) was observed higher fruit diameter (cm) as compared to control. The maximum fruit diameter (cm) was recorded in treatment T_5 (5.82 cm), which was at par with T_4 (RDF + 0.75 hydrogel). Yield parameters increased with increased levels of hydrogel. RDF + 1.0 hydrogel significantly improved the fruit weight, number of fruits, fruit diameter and fruit yield due to increased uptake of N, P and K which resulted in increased number of branches as well as biomass. Under limited water condition hydrogel was able to retain higher moisture in the crop root zone and help the plant to sustain against drought condition. Further, it also helps nutrients uptake at proper ratio by increasing nutrient holding capacity and their subsequent release. Similar findings were reported by Hamid et al. (2013) in ground nut, Meena et al. (2011) in tomato crop.

4. CONCLUSION

On the basis of this experimentation, it is concluded that RDF + 1.0 hydrogel (T_5) in tomato should be applied for better nutrient and water management throughout the cropping season for obtaining higher yields and economic returns over rest of the treatments.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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