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Soil Water, Plant Yield and Root Dynamics under Application of Super Absorbent Polymers (SAP) in Semi-Arid Alfisols

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ABSTRACT: The Semi-arid alfisols are predominant in rainfed agriculture having very low water holding capacity and surface crusting necessitating the adoption of water conservation technologies for drought management. Laboratory experiments were conducted in loamy sand for physical characterization of super absorbent polymers. Four polymer products (P1, P2, P3 and P4) of the commercial value with different concentrations (0.25%, 0.75%, 1.25% and 1.75%) were used and compared with control (soil without polymer). Among four polymer products tested, SAP P3 showed maximum water absorption of 312 g g^{-1}. Maximum soil moisture content of 42% and minimum of 20% was observed at field capacity (0.3 bar) and permanent wilting point (15 bar) with 1.75% SAP concentration. The experiment on water productivity with tomato was carried out with P3 having maximum water absorption at 50 and 80% moisture depletion levels and 0.25, 0.5 and 0.75% polymer concentrations in growth chambers. Significant difference (p=0.05) was observed among different polymer concentrations at 50% soil moisture depletion level. The maximum yield in tomato (2.71 kg/plant), water productivity (318.52 kg m^{-3}), water saving (69.3%) and 90% enhanced root growth were obtained with 0.75% polymer concentration (P3) at 50% soil moisture depletion.

Key words: Water absorption rate, soil water holding capacity, water productivity, tomato, root biomass

Alfisols, the most abundant soils in the semi-arid tropics, cover nearly 33% of the SAT region. They occur extensively in southern Asia, Western and Central Africa, and many parts of the South America, particularly northeast Brazil. Alfisols of the semi-arid tropics are often characterized as structurally unstable possessing inherently low water retention characteristics because of their particle size make up and mineralogical composition. This is often compounded by the shallow depth of the soil zone available for water storage combined with mechanical impeditive problems in these hardening soils to limit crop-root proliferation.

The soil related constraints combined with SAT environment result in uncertainties and considerable risk to agricultural systems. Due to these, the current agricultural productivity on these soils in most SAT regions remains low. With the current land use system, the rainfall use efficiency of the rainfed production systems are low, ranging from 35-55%, and major portion of rainfall is lost as surface runoff, evaporation and deep drainage from the soil. Super absorbent polymers (SAPs) are cross-linked polymers and can absorb large volumes of liquid. Superabsorbent polymer (SAP) is a water retaining, cross-linked hydrophilic, biodegradable amorphous polymer which can absorb and retain water at least 400 times its original weight and make at least 95% of its stored water available for plant absorption. When mixed with soil, it forms an amorphous gelatinous mass on hydration and is capable of absorption and desorption over long period of time, hence acting as a slow-release source of water in the soil.

In arid and semi arid regions, the use of SAP in the sandy soil (macroporous medium), to increase its water-holding capacity seems to be one of the most significant means to improve the quality of plants (Bakass *et al.,* 2002; Casquilho *et al.,* 2013). The SAP particles may be taken as "miniature water reservoirs" in the soil by restricting the movement of water from sub-surface layer to surface layer and water will be removed from these reservoirs upon the root demand through osmotic pressure difference. More available water in the soil also means less frequent watering or reducing irrigation frequency for field grown crops besides reducing irrigation amount from 100 to 85% of the crop water requirements and increase crop yield (El-Hady and Wanas, 2006). Super absorbent polymers do not threat human life and environment (Boatright *et al.,* 1997). Due to the bonding effect of hydrogel molecules with sandy particles and their swelling capacity, an improved and stable structure of the sandy soil is obtained. Kokhaei (2003) reported that superabsorbent polymers can increase fresh root weight in tomato and melon. Hydrogel-treated plants had approximately 3.5 fold higher root length and root surface area than those grown in untreated saline soil. The improved physical properties reported were better aggregation of soil particles, improved water use efficiency, reduced infiltration rate, increased water holding capacity and decreased evaporation losses (Ekebafe *et al.,* 2011) and reduce negative effects of water shortage on plants (Sayyari and Ghanbari, 2012). Therefore, an experiment was conducted to understand the abilities of the SAP and evaluated its effect on water productivity of tomato under rainfed Alfisols.

Materials and Methods

Laboratory experiments were conducted at Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad. Soil was collected randomly from agricultural field in Gunegal Research Farm, which is located 50 km away from Hyderabad. The latitude and longitude of the farm are 17.080

N and 78.660 E. The average annual rainfall is 750 mm with maximum temperature and minimum temperature of 37^{0}C and 15^{0}C, respectively. The field selected for sampling is of loamy sand texture and low in water holding capacity. The physical and chemical properties of the soil are sand (84%), silt (12%) and clay (4%) with bulk density of 1.63 g cc^{-1} and field capacity of 16% and permanent wilting point was 8.4% wt/wt and infiltration capacity of 3.5cm hr^{-1}. The pH and electrical conductivity were 5.35 and 0.56 dSm^{-1}. Four SAPs were obtained from M/S Saveer Bio-Tech Ltd, New Delhi. The trade names of the products are RDW-N, RDW-I, RDW-W and RDW-F. These products are procured for research purpose only to evaluate the applicability of such products in rain water management in SAT regions/ rainfed regions. The authors are not bound legally for commercial exploitation of the product evaluation results as the present research was done on limited scale in confined manner. For experiment purpose, the products are renamed as P1, P2, P3 and P4 for RDW-N, I, W and F, respectively were of white granules in structure and appearance, pH value ranging from 6.5-8.5, moisture holding capacity more than 7% by weight, absorbance of destined water form ≥380 to 520 g g^{-1}.

The soil samples were air dried without moisture and it was sieved through I.S. 2mm sieve. These samples were used for studying the physical characteristics of the four SAPs in different ratios of mixing of SAP. The treatments included in the present study are soil with no SAP (T_1) as control, soil with 0.25% (T_2), 0.75% (T_3), 1.25% (T_4) and 1.75% of SAP (T_5), respectively. The treatments were replicated three times with each SAP and the average values were taken for analysis in physical characterization of soil with SAP.

Water absorption characteristics and holding capabilities of SAP

Polymer of 1g was placed in 400 ml of tap water in 1000 ml beaker and it was weighed after 30 min interval till the maximum absorption rate was obtained for each SAP. Excess water was drained out by passing the SAP through porous sieve under the tap water by weighing the individual SAP sample. The water used in the study has pH of 7.5 and EC of 1.26 dS/m. It was replicated 3 times for each SAP and average water absorption was calculated. The water holding characteristics of soil with four SAPs were determined in the laboratory using a pressure plate apparatus at field capacity (0.3 bar) and wilting point (15 bar). Soil sample mixed with each SAP of 40g at selected application rate (T1-T5) was first saturated for 12h duration as per standard procedure. The saturated sample was kept inside the rings of the pressure plate apparatus and it was subjected to 0.3 bar and 15bar. The procedure was repeated for all SAP with different application rates. The total procedure was repeated 3 times to determine average soil moisture content at 0.3 and 15 bar of each soil sample. All soil moisture contents were calculated on gravimetric basis.

Effect of SAP on water productivity

The growth chambers of size 30 x 15 x 45 cm of 12 numbers were used in the net house for the experiment on water productivity and followed the methodology of Maruthi *et al.* (2013). Based on the performance indication of maximum water holding capacity, among the four SAP products, P3 was selected for the experiment on water productivity. In the experiment, SAP P3 was mixed with soil in the ratios of 0, 0.25, 0.5 and 0.75% by weight with 3 replications. Each chamber was irrigated at two depletion levels of 50% and 80% by volume. The volume of water was calculated for both 50 and 80% depletion levels from the field capacity. The soil moisture at field capacity were taken from laboratory analysis (Figure 3a and b). Soil moisture readings were recorded on weekly basis since from the date of transplanting of tomato nursery plants into the chambers. Biometric measurements like plant height, number of branches and stem girth were recorded. Finally the yield data from each plant was recorded and analyzed for water productivity (Sivapalan, 2001). Test crop tomato (*Lycopersicon esculentum* Mill.) was grown acrylic root chambers to have the total depth of 45 cm. The root system was carefully collected and washed and oven dried at 60°C for dry weights. The data were analyzed with standard statistically package of Completely Randomized Block Design (CRBD). The 'f' test was calculated and critical difference values were worked out at 5% probability level.

Results and Discussion

Water absorption characteristics and absorption rates of SAPs

All four SAP polymers had a similar pattern in the rate of water absorption. Polymers P_1 and P_2 showed rapid initial hydration than P_3 and P_4 followed by a progressive decrease in the rate of absorption towards the point of equilibrium (Figure 1). The initial rate of absorption by polymers in 5min was more in Polymer P_1 (114 g) followed by P_2 (87 g), P_4 (70 g) and the least in P_3 (51g). Water absorption by SAPs increased with time having the absorption of 161 g, 135 g, 130 g and 117g in Polymers P_1, P_2, P_3 and P_4 after 30 min. Depending upon their density of the cross-linkages, polymers P_1 and P_2 attained full capacity in about one hour of 181 g and 154 g. Polymer P_1 reached its maximum capacity of 156 g in 75 min which was more than Polymers P_2, P_3 and P_4. Polymer P_3 a slow hydrating polymer compared to other three polymers continued to absorb water upto 280 min, until it reached its peak retention capacity with maximum absorption of 312 times to its weight. Polymer P_3 showed more water absorption than other polymers. This may be

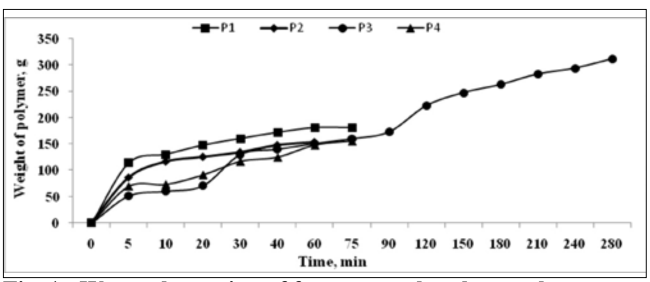

Fig. 1 : Water absorption of four super absorbent polymers

In the initial time of 5 min duration, the hydration or water absorption ra te of SAPs were found maximum with maximum rate of 22.8 g min^{-1} in P1 followed by 17.3 g min^{-1} in P2, 14 g min^{-1} in P4 and lowest rate of 10.3 g min^{-1} in P3 (Figure 2). All the SAPs except P3 continued to absorb water for 75 min and P3 continued to absorb water for more than 4hr period (280 min). The slow rate of water absorption by polymers may be beneficial to the plant roots to grow into the soil profile for sustaining the plant as the polymer allows water to infiltrate into the soil beyond its point of application.

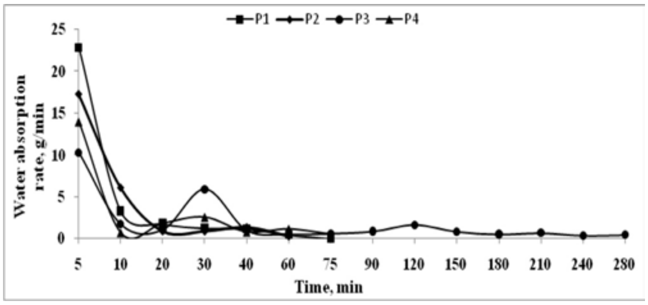

Fig. 2 : Water absorption rate of four super absorbent polymers

Soil moisture characteristics of SAPs

The mixture of SAPs with soil improved its moisture content substantially at field capacity. The SAP P3 resulted in the maximum soil moisture contents of 22.3%, 29.6%, 34.8% and 42% at the concentrations of 0.25, 0.75, 1.25 and 1.75, respectively (Figure 3a). Among the SAPs, P3 is followed by P1, P2 and P4 in their order of performance. The SAP P4 resulted in the minimum values of soil moisture contents of 19.7%, 22.4%, 25.6% and 29.7% at the concentrations of 0.25, 0.75, 1.25 and 1.75 respectively. At wilting point of 15 bar, the bare loamy soil moisture content obtained was 5.4%. But the loamy soil mixed with SAPs improved soil moisture contents increased with increase in ratio of mixing SAP. However, the SAP P3 exhibited the maximum release of water into the soil at 15 bar as compared to other three SAP's (Figure 3b). SAP P2 had maximum moisture content, still holding water after 15 bar suction created in the pressure plate apparatus at all ratios of mixing followed by P1 and P4. But, P2, P1 and P4 showed the slow release of water at 15 bar suction as compared to P3. The results presented in (Figure 3c) indicate that the maximum available water is seen with SAP P3 when mixed with loamy sand at all ratios as compared to other SAPs. The maximum available water for P3 was of 0.27, 0.36, 0.40 and 0.44 m m^{-1}. P3 is followed by P1, P2 and P4 in their order. The available water obtained from P4 was more or less equivalent to the values of control without mixing polymer. The above results indicated that the performance of SAP P3 was the best in terms of water holding and releasing characteristics at field capacity and permanent wilting point as compared to other three SAPs. It is because that P3 exhibited the maximum release of water having less moisture varying from 7 to 15% at different concentrations at PWP of 15 bar as compared to other SAPs. It enhances the water availability to plants at maximum stress level of PWP. Therefore, the performance of P3 was tested with Tomato crop in the loamy sand soil in the net house.

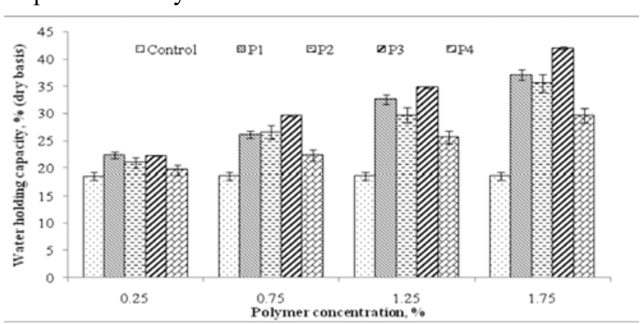

Fig. 3(a) : Water absorption rate of four super absorbent polymers at field capacity

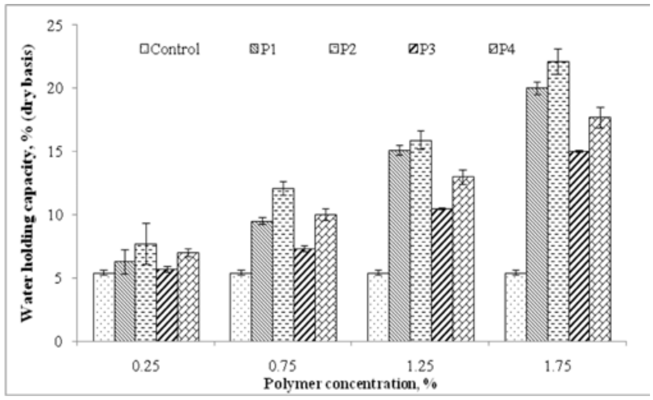

Fig. 3b : Water absorption rate of four super absorbent polymers at permanent wilting point

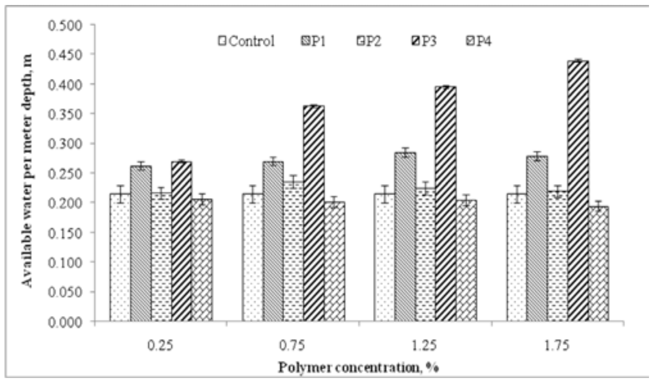

Fig. 3c : Available water per meter depth of loamy sand soil and four super absorbent polymers

Effect of SAP P3 on plant growth parameters

The results regarding growth parameters like plant height, number of branches and stem girth and their interaction with SAP concentrations at different moisture depletion levels are presented in Table 1. Maximum values of plant height, number of branches and stem girth were 96 cm, 19 nos and 1.7 cm of plant, respectively at 50% moisture depletion with 0.75% SAP application in loamy sand soil. The growth parameters were decreased in 80% depletion level at all application rate of SAP than soil at 50% depletion and they are not significant at 5% probability. Moreover, the growth parameters are observed to be significant over the control at 5% level at 50% moisture depletion, respectively. There is a significant difference in number of branches at 0.75% SAP application rate with maximum of 19 at 50% moisture depletion level. However, there is a increase observed over the control in all growth parameters with different SAP application rates and different moisture levels. Similar results were obtained showing the increased growth of plant parameters when sandy loam soil mixed with SAP in different crops (Yazdani *et al.,* 2007).

Crop yield and water productivity with SAP P3

SAP P3 was chosen for testing its performance on crop growth, yield and water productivity and exhibited the better water absorption and release characteristics with the sandy loam soil. The results obtained relating yield and water productivity in tomato crop under two different soil moisture depletion levels (50% and 80%) are presented in Table 1 for various treatments of application rates of SAP P3 with the soil. Among the treatments, the tomato fruit yields are significant over the control.

Table 1 showed that the maximum average yield of 2.71 kg/ plant was obtained in the treatment of 0.75% SAP P3 at 50% depletion level of soil moisture from field capacity as the number of branches was maximum followed by 2.34 kg/ plant at 80%. Similarly with 0.5% polymer concentration, average yield of 2.12 kg/plant was obtained at 50% depletion level and 1.52 kg/ plant at 80% depletion level. In control, an average yield of 0.52 kg/plant was recorded at 50% depletion and 0.32 kg/plant at 80% depletion level which was minimum when compared to other treatments. The average yields of tomato decreased with 80% moisture depletion over the 50% depletion level, which is normally due to the water stress affecting the plant growth. Though the average yields were increased over the control at all application rates of SAP and two moisture depletion levels, they were significant at 5% probability level. However, the average yields are significantly different among the different application rates of SAP and over the control. Among all the application rates of SAP, 0.75% SAP was observed to be more efficient at 50% moisture depletion level in tomato crop. Similarly, the water productivity was maximum (318.82 kg m^{-3}) with 0.75% application rate of SAP at 50% moisture depletion level and 240.74 kg m^{-3} at 80% depletion level followed by 194.05 kg m^{-3} and 93.57 kg m^{-3} with 0.50% application rate at 50% and 80% depletion levels, respectively. Similarly with 0.25% SAP application rate, water productivity of 49.88 kg m^{-3} and 38.99 kg m^{-3} were recorded. Control showed a minimum water productivity of 16.25 kg m^{-3} at 50% depletion level and 13.65 kg m^{-3} at 80% depletion level.

Table 1 : Plant growth parameters, average yield and water productivity of tomato with different polymer concentrations and moisture

Treatments	Plant growth parameters at different depletion levels						Average yield and water productivity					
	Plant height, cm		Number of branches		Stem girth, cm		Tomato yield, kg/plant		Water productivity, kg m^{-3}		Water applied, litres	
	50%	80%	50%	80%	50%	80%	50%	80%	50%	80%	50%	80%
0% (Control)	90	87	14	10	1.37	1.15	0.52	0.32	16.25	13.65	27.69	30.78
0.25% of SAP	92	90	16	13	1.50	1.51	1.19	0.93	49.88	38.99	17.04 (38.5%)	20.52 (33.4%)
0.50% of SAP	95	92	16	15	1.64	1.49	2.12	1.52	194.05	93.57	12.78 (53.9%)	13.68 (55.6%)
0.75% of SAP	96	91	19	16	1.67	1.57	2.71	2.34	318.82	240.74	8.52 (69.3%)	9.72 (68.5%)
Mean	93	90	16	13	1.55	1.43	1.64	1.28	143.21	127.65	-	-
SEm±	1.45	1.42	1.380	1.26	0.15	0.19	0.16	0.09	11.79	8.05	-	-
CD (P=0.05)	4.73	4.65	4.49	4.13	0.50	0.65	0.51	0.29	38.44	26.91	-	-

Note: There is no significant difference among the depletion levels at 5% probability level.

Effect of SAP P3 on root growth

The SAP P3 polymer had positive influence on dry weight of tomato root. Among different concentrations of SAP P3 polymer, the maximum dry weight of tomato root (43.48 g) was observed in 0.75% and minimum (10.87 g) dry weight was noticed in control (Figure 4). It is observed that, as the concentration of polymer increased, the dry weight of tomato root also increased. It may be due to that, the increased concentration of polymer increases the available water in the crop root zone, which positively increased the root length leading to increased root weight. The same results were also reported by Kokhaei (2003) for tomato and melon. SAP at 0.75% concentration both at 50% and 80% depletion levels recorded maximum root growth. However, the maximum dry weight or root at 80% moisture depletion was not realized in the form of yields as was realized in the 50% moisture depletion since the rate of root proliferation was not directly related to the yields especially when the photosynthates be utilized more for increased root growth and hence the reduced yields at this level.

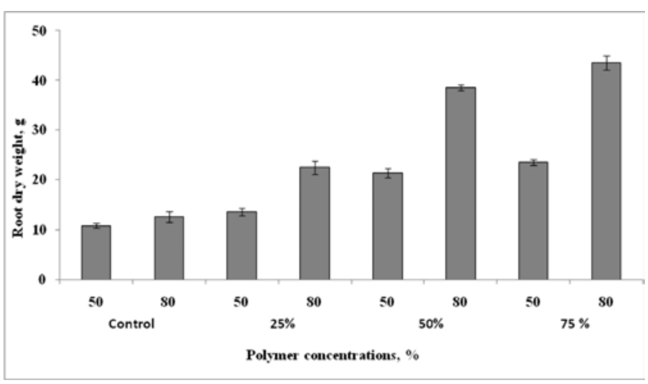

Fig. 4 : Dry weight of tomato root under different polymer concentrations at 50 and 80% moisture depletion level

Conclusions

It was observed that, SAP P3 had maximum available water content as compared to all other polymers in application rates. In view of these results, it was found that, there was significant difference among SAP concentrations at 5% probability in respect of growth parameters, average yield and water productivity. Although, super absorbent polymer application improved root biomass of plants under drought stress by 90% at 0.75% SAP conc. at 50% moisture depletion, it helped in realizing maximum yield and water productivity. The maximum average yield was obtained with 0.75 application rate of SAP P3 at 50% moisture depletion. Therefore, it is concluded that, 0.75% application rate and irrigation scheduling at 50% moisture depletion can be recommended for semi-arid loamy soils for tomato with maximum yield of 2.75 kg/plant, water productivity of 318.82 kg m^{-3} and water saving of 69.3% over the soil without SAP application.

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