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Influence of Super Absorbent Polymers on Infiltration Characteristics of Alfisols in Semi- Arid Region

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ABSTRACT: Infiltration characteristics of the soil are important to understand the water dynamics in the root zone of a soil-plant system. A laboratory experiment was conducted to study the infiltration characteristics of sandy loam soil under different application rates of super absorbent polymers (SAPs). 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 reduction (90%) in the steady state infiltration rate as compared to P1, P2 and P4 tested over different concentrations. The steady infiltration rate was decreased by 3.6 to 1.75, 4.1 to 0.4, 1.4 to 0.52 and 1.6 to 0.76 cm/hr under P1, P2, P3 and P4, respectively in the polymer concentrations of 0.25, 0.75, 1.25 and 1.75%. The infiltration data were fitted to Philip model and model parameters had the best description of the relationship between infiltration rate and application rate of super absorbent polymers in the sandy loam soil with significant reduction in saturated hydraulic conductivity (A) varying from 12.4 to 84.75%. Out of four polymers tested, P3 had more reduction capacity in the infiltration rates of sandy loam soils as compared to other SAPs.

Key words: Infiltration rate, alfisols, super absorbent polymers, Philips model, semi-arid region

Alfisols are the major soil orders in the semi-arid tropics (SAT) which cover nearly 33% of the SAT region (Pathak *et al.,* 2013). In most semi-arid regions, rainfall distribution is highly erratic with frequent dry spells within the rainy season (Reddy *et al.,* 2012; Virmani *et al.,* 1991). The soils related constraints such as shallow depth, low water-holding capacity and coarse texture, contain low organic matter and are subjected to severe erosion, leading to poor water and fertilizer use efficiency by plants resulting to uncertainties and considerable risk to agricultural systems. Due to these constraints, the current agricultural productivity on these soils in most SAT regions remains low (Wani *et al.,* 2009). Pathak *et al.* (2009) reported that in the semi-arid alfisols, the rainfall use efficiency of the production systems ranged between 35 and 55%, thus a large percentage of annual rainfall is lost as surface runoff, evaporation and deep drainage which can be harvested and utilized for crop production. Thus, new strategies and more appropriate soil and water management systems are required to tackle water related constraints in alfisols which combine the effective conservation and utilization of soil and water resources to increase productivity.

Superabsorbent polymers (SAPs) are also called soil polymers or macromolecular polymers, which are capable of repeatedly absorbing, retaining and releasing extremely large amounts of water relative to their own weight (Linlin Yang *et al.,* 2015). Thus, they can improve water conservation in soils, prevent deep percolation and soil nutrient loss, and maximize the use efficiency of water and fertilizer (Liu and Rempe, 1997 & Beckett and Augarde, 2013). SAPs are mostly used in arid and semi-arid regions to overcome water scarcity problem. They enhance both the nutritional and water status of plants. It has been reported that they are capable of retaining water up to 500 times of their weight (can build an additional water reservoir for the plant-soil-system (Bouranis *et al.,* 1995 and Buchholz, 1998). SAPs can be efficiently used to reduce erosion, runoff and soil losses, decreasing the infiltration rates of water into the soil, and increasing the hydrophilic nature of the soil surface which aids seed germination and emergence (Roqieh Barihi *et al.,* 2013). Shahrokhian *et al.* (2013) used polymers as soil conditioners for improving the unfavorable soil condition like very high infiltration rate and concluded that, super absorbent polymers can be effectively used to reduce the infiltration rate of soil.

The application of SAPs improved physical properties of soil, water use efficiency, reduced infiltration rate, increased water holding capacity and decreased evaporation losses (Choudhary *et al.,* 1995; Shooshtarian *et al.,* 2012). Zhuang *et al.* (2013) used different concentration of SAPs from 0 to 1%, on water retention, saturated hydraulic conductivity (Ks), infiltration characteristics and water distribution profiles of a sandy soil and reported that water retention and available water capacity effectively increased with increase in SAP rate. However, infiltration was significantly reduced by increasing SAP rate, which effectively reduced water in a sandy soil leaking to a deeper layer under the plough layer. The use of cross- linked polyacrylamides was tested to increase the water holding capacity of sandy soils (Xu S.T. *et al.,* 2014). The water stored in this way is available to plants for some considerable time. Due to the bonding effect of hydrogel molecules with sandy particles and their swellability, an improved and stable structure of the sandy soil is obtained. Polyacrylamides in soil were also able to reduce the amount of water lost from the soil through evaporation (Cannazza *et al.,* 2014).

The application of SAPs in agriculture is generally studied by qualitative researches on the effect of polymers on crops and soil water content (Baasiri and Rvan, 1986; Yazdani *et al.,* 2007; Bai *et al.,* 2010 and Han *et al.,* 2010). However, only few quantitative researches are conducted on the redistribution of the wetted pattern and water content in soils caused by changes in the mechanical composition of soils due to the application of SAPs and on the soil water dynamics caused by the application of SAPs. Keeping these points in mind, the present study was undertaken to know the infiltration characteristics of different concentrations of super absorbent polymers (SAPs) in rainfed alfisols.

Materials and Methods

Laboratory experiments were carried out at CRIDA, Hyderabad. Four SAPs were obtained from M/S Saveer Bio-Tech Ltd, New Delhi. The trade names of the products are RDN-W, RDW-I, RDW-W and RDW-F. These products are procured for research purpose to evaluate the applicability of such products in rain water management in rainfed horticulture. For experiment purpose, the products are renamed as P1, P2, P3 and P4 for RDN-W, RDW-I, RDW-W and RDW-F, respectively. These products were of white granules in structure and appearance, having 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.

The soil samples were air dried, ground and passed through 2mm sieve. The physico-chemical characteristics are given in Table 1. Five measuring cylinders of 1000 ml capacity were taken. Soil samples mixed with each SAP application rates of 0, 0.25, 0.75, 1.25 and 1.75% by weight were filled with each cylinder maintaining same compaction of 500 g soil. Infiltration of loamy sand soil was conducted in the laboratory with SAP application in different rates by weight as per the procedure suggested by Shinde and Bangal, 1992. One each 300 ml of tap water was added to each cylinder. The fall of water level was recorded at fixed time interval to calculate the infiltration rates. The above experiment was replicated 3 times for each sample of SAP. The treatments were replicated three times with each SAP and the average values were taken for analysis in physical characterization of soil with SAP.

Infiltration models

Among many models developed for monitoring the infiltration process, Philip, Horton and Kostiakov models have been studied in detail because of their simplicity and the ease of estimating their fitting parameters (Mbagwu, 1994). Reddy *et al.* (2013) had used these models to study infiltration characteristics of alfisols and concluded that, the Philip model was observed the best fitted with observed data followed by modified Kostiakov and Horton. Hence, only Philips model was chosen to study infiltration characteristics of super absorbent polymers in rainfed alfisols.

Table 1 : Physical and chemical characteristics of soil

Parameters	Value
Sand, %	84
Silt, %	12
Clay, %	4
pH	5.35
Electrical conductivity, dS/m	0.56
Bulk density, g/cc	1.63
Field capacity, %	16
Permanent wilting point, %	8.4
Infiltration capacity, cm/hr	3.5

Philip model

Philip proposed an infiltration model in 1957 and this is a process-based infiltration model. Once the soil sorptivity and soil saturated hydraulic conductivity are obtained, the Philip model can be set up (Runbin Duan, *et al.,* 2011) as given below:

$$f(t) = (S/2)\, t^{-1/2} + A \qquad \text{……....1}$$

Where f(t) is infiltration rate (cm/hr), S is sorptivity of soil (cm), and A is a constant (cm/hr)

The above model was used to determine the co-efficients for different application rates of SAPs by using curve expert software version 2.2.

Results and Discussion

Infiltration characteristics of semi-arid alfisols with selected super absorbent polymers under different concentrations were studied and results obtained during experiment were presented in this section. The infiltration characteristics under 0.25% concentration is presented in Figure 1(a). P1 and P3 registered same initial infiltration rate of 14 cm/hr followed by P2 (13.6 cm/hr) and least was in P4 (9.2 cm/hr) observed among the selected polymers. The highest steady infiltration rate (SIR) after 120 min was observed in P2 (4 cm/hr) followed by P1 (3.6 cm/hr), P4 (1.6 cm/hr) and least was in P3 (1.4 cm/hr). The differences between infiltration rates with P1, P4 and P3 are significant ($P<0.05$).The time taken to achieve steady infiltration rate was least in P1 (75 min) followed by P2 (90 min), P4 (90 min) and highest was in P3 (105 min). Under 0.75% polymer concentration, the highest initial infiltration rate of 11.4 cm/hr was observed in P1 followed by P2 (11.2 cm/hr), P3 (10.2 cm/hr) and least was in P4 (8.88 cm/hr) observed among the selected polymers (Figure 1(b)). The highest steady filtration rate after 120 min was observed in P1 (2 cm/hr) followed by P4 (1.28 cm/hr), P3 (1.0 cm/hr) and least was in P2 (0.4 cm/hr).

The infiltration characteristics under 1.25% concentrations are presented in Figure 1(c). The highest initial infiltration rate 8 cm/hr was observed in P2 followed by P1 (5.4 cm/hr), P4 (4.8 cm/hr) and least was in P3 (4.6 cm/hr) among the selected polymers. The highest steady infiltration rate after 120 min was observed in P1 (1.8 cm/hr) followed by P4 (0.8 cm/hr), P3 (0.6 cm/hr) and least was in P2 (0.4 cm/hr). The time taken to achieve steady infiltration rate was minimum in P1 (60 min) followed by P3 and P4 (each 75 min) and maximum was in P2 (90 min). Under 1.75% concentration, there was no infiltration during first 15 min except in P4 (2.6 cm/hr). After 45 min, the highest initial infiltration rate (5.1 cm/hr) was observed in P1 followed by P3 (3.9 cm/hr), P4 (1.8 cm/hr) and least was in P2 (1.6 cm/hr) among the selected polymers (Figure 1(d)). The highest steady infiltration rate after 120 min was observed in P1 (1.4 cm/hr) followed by P4 (0.76 cm/hr), P3 (0.52 cm/hr) and least was in P2 (0.4 cm/hr). The time taken to achieve steady infiltration rate in P1 and P2 was 75 min followed by P3 and P4 (90 min). Similar results were seen in Shinde *et al*. (1992) and they reported decrease in infiltration rate with time and increase in doses of Jalashakti polymer in clay loam, silty loam and loamy soils.

The results of steady state infiltration rate (SIR) observed at 120 min under different application rates of SAPs are presented in Table 2. The steady state infiltration rate of sandy loam was 4 cm/hr at 120 min. The results clearly indicated that, steady state infiltration rate decreased with increase in application rate. The maximum SIR (3.6 cm/hr) was observed in 0.25% followed by 2.1, 1.8 and least 1.4 cm/hr was in 0.75, 1.25 and 1.75% under P1, respectively. Under P2, the maximum SIR (4.1 cm/hr) was in 0.25 % and there was no significant change observed in 0.75-1.75% (0.4 cm/hr). The maximum SIR (1.4 cm/hr) was observed in 0.25% followed by 1.2, 0.6 and least 0.52 cm/hr was in 0.75, 1.25 and 1.75% under P3, respectively. The maximum SIR (1.6 cm/hr) was observed in 0.25 % followed by 1.28, 0.8 and least 0.76 cm/hr was in 0.75, 1.25 and 1.75% under P4, respectively. The effects of SAPs on soil infiltration capacity had close relationship with its application rates which lead more water absorbency and swelling characters. Similar results were also obtained by Zhuang (2013), and showed that water retention and available water capacity effectively increased with increase in SAPs rate. The Ks and the rate of wetting front advance and infiltration under certain infiltration was significantly reduced by increasing SAPs rate, which effectively reduced water in a sandy soil leaking to a deeper depth under the plough layer.

Table 2 : Average steady state infiltration rate (cm/hr) under different application rates of SAP

Application rate, %	Super Absorbent Polymers			
	P1	P2	P3	P4
0.25	3.6 ± 1.25	4.1 ± 1.51	1.4 ± 1.00	1.6 ± 1.48
0.75	2.1 ± 1.25	0.4 ± 0.1	1.2 ± 1.00	1.28 ± 1.08
1.25	1.8 ± 0.54	0.4 ± 0.34	0.6 ± 0.49	0.8 ± 0.46
1.75	1.4 ± 0.52	0.4 ± 0.24	0.52 ± 0.38	0.76 ± 0.26
Control	4.0 ± 1.66	4.0 ± 1.66	4.0 ± 1.66	4.0 ± 1.66

± indicates standard error of mean

Infiltration reduction under different SAP concentrations

The results of percentage reduction in infiltration rates (cm/hr) at initial and final condition of sandy loam soil with polymers over control (without polymer) are presented in Figure 2. The percentage reduction under 0.25% concentration ranged between 12.5 and 42.5% during initial condition for P1, P2, P3 and P4 polymers, respectively. During final condition, the maximum percentage reduction was observed in P3 (87.5%) followed by P2 (65%), P4 (60%) and minimum was in P1 (10%). The maximum rate of infiltration reduction under 0.75% concentration was (44.5%) observed in P4 followed by P3 (36.25%), P2 (30%) and least was in P1 (28.75%) during initial condition and the maximum percentage reduction was observed in P3 (90%) followed by P2 (75%), P4 (68%) and minimum was in P1 (50%) during steady state condition. The maximum rate of infiltration reduction under 1.25% concentration was 70% observed in P4 followed by P3 (65%), P2 (50%) and least was in P1 (43.75%) during initial condition and the maximum percentage reduction was observed in P3 (90%) followed by P2 (85%), P4 (80%) and minimum was in P1 (55%) during steady state condition.

The maximum rate of infiltration reduction under 1.75% concentration was 83.75% in P4 followed by P3 (75.63%), P2 (68.75%) and least was in P1 (56.25%) during initial condition and the maximum percentage reduction was observed in P3 (90 %) followed by P2 (87%), P4 (81%) and

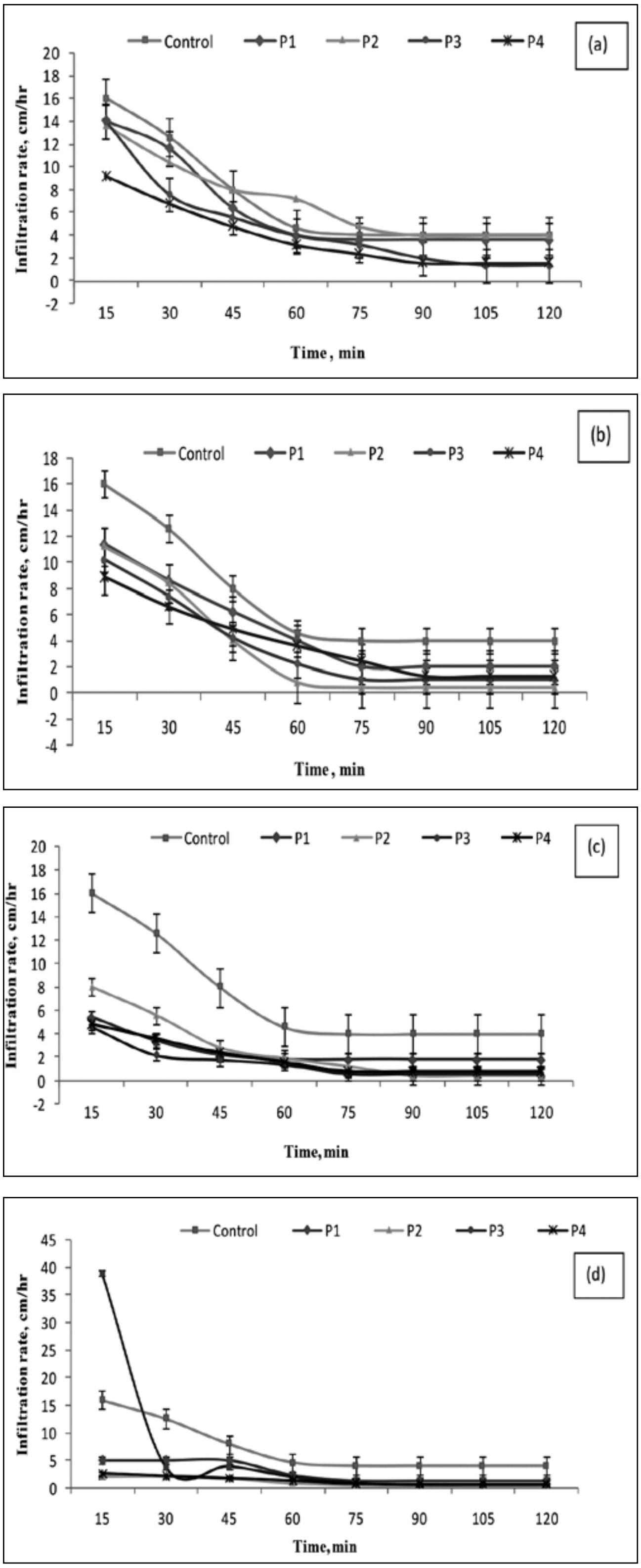

Fig. 1 : Infiltration characteristics of sandy loam soils with selected super absorbent polymers under different concentrations

minimum was in P1 (65%) during steady state condition. It is observed that, the percentage reduction increased as polymer concentration increased from 0.25 to 1.75%. Shane Phillips (2007) showed that PAM-1011 can significantly reduce steady-state infiltration rates in a range of relatively coarse sandy soils. Holding more soil moisture and decreasing infiltration rate will be very useful in bringing the alfisols to a good condition required for crop growth.

Estimated Philip model constants under application of SAPs

The infiltration data of different concentration of SAPs were fitted to Phillip and estimated model coefficients are presented in Table 3. The saturated hydraulic conductivity (A) in Philip's model had definite trend in the different concentration of SAPs as compared to control. The parameters of Phillip's equations suggest that the saturated hydraulic conductivity was influenced with significant reduction with increase in SAPs concentration from 0.25 to 1.75%. Under the concentration of 0.25%, the 'A' (cm/hr) value decreased by 7.07 (-12.39%), 6.91 (-14.37%), 6.84(-15.24%) and 4.86(-39.77%), respectively under P1, P2, P3 and P4 as compared to control (8.07). Under SAPs concentration of 0.75%, the 'A' value decreased by 6.10 (-24.41%), 6.09 (-24.53%), 5.42 (-32.83%) and 4.85 (-39.90%) against control (8.07) in P1, P2, P3 and P4, respectively. There was a reduction of 'A' value by 4.29 (-46.84%), 2.54 (-68.52%), 2.31 (-71.37%) and 2.15 (-73.35%) under 1.25% concentration of SAPs in P1, P2, P3 and P3 as compared to control. The same trend also observed under 1.75 % of SAPs by 3.16 (-60.84%), 1.41(-82.52%), 1.53(-81.04%) and 1.23(-84.75%) in P1, P2, P3 and P3 as compared to control. The maximum reduction in 'A' was observed in 1.75% application of rate of SAPs in semi arid sandy loam soils indicating the possible reduction in deep percolation losses in the sandy loam soils leading to more available water within root zone to the plants for their extraction.

The cause of the decrease of 'A' value may be due to the fact that, the water absorption by SAPs increased with increase in SAPs concentration and then the expansion increased the paths for infiltration of water, and secondly the viscosity of SAPs itself become bigger, which increased the resistance against the migration of water downward in the soil. These results are in line with Zhuang *et al.* (2013). They reported that, the increase in concentration of SAPs into sandy soil can decrease the saturated hydraulic conductivity and infiltration capacity of water into deep layer under the saturation state, and the larger the application amount, the larger is the decreased degree, which is helpful to store water within a certain arable layer. In general, the sorptivity, S, increased with increase in concentration of SAPs from 0.25 to 1.75% in all the treatments. The highest reduction (-0.91, -0.71, -0.57 and -0.52 cm/hr) was observed under 0.25, 0.75, 1.25 and 1.75%, respectively under P3 as compared to -0.49 cm/hr in control.

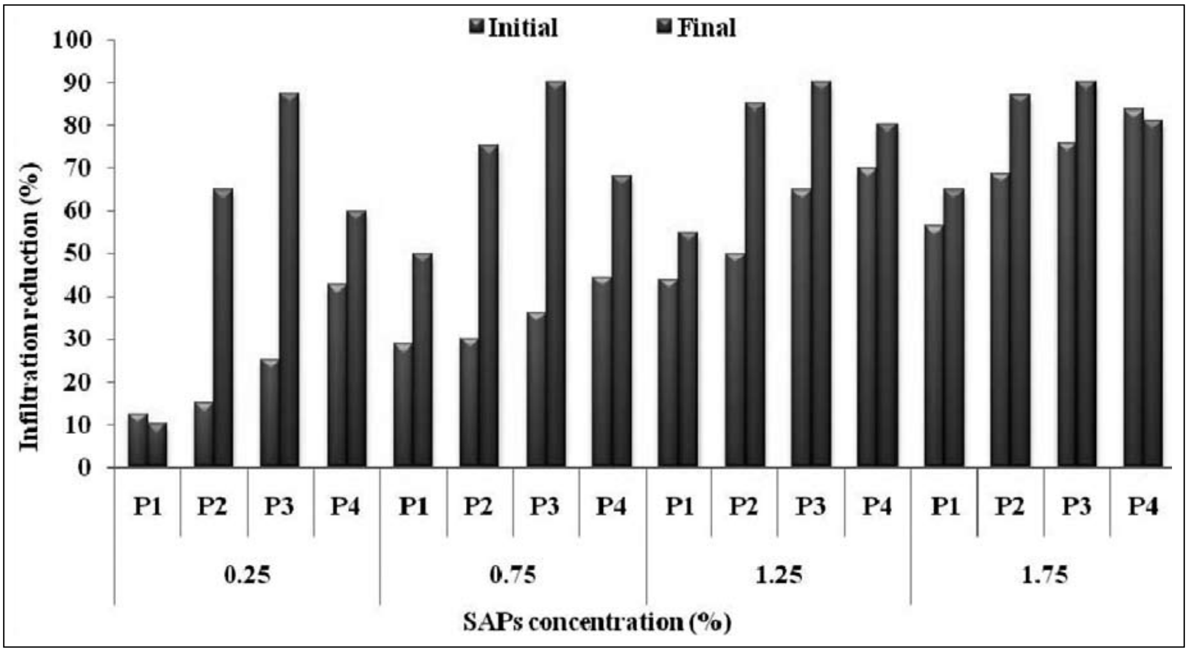

Fig. 2 : Percent reduction in the initial and final infiltration rates in sandy loam soil under different concentrations of super absorbent polymers

Table 3 : Estimated infiltration model coefficients under different SAPs concentrations

Treatments	Infiltration rate	Philip constants	
		S (cm/hr)	A (cm/hr)
Control	0.25 % concentration	-0.49	8.07
P1		-0.42	7.07
P2		-0.20	6.91
P3		-0.91	6.84
P4		-0.40	4.86
Control	0.75 % concentration	-0.49	8.07
P1		-0.53	6.10
P2		-0.66	6.09
P3		-0.71	5.42
P4		-0.43	4.85
Control	1.25 % concentration	-0.49	8.07
P1		-0.03	4.29
P2		-0.22	2.54
P3		-0.57	2.31
P4		-0.23	2.15
Control	1.75 % concentration	-0.49	8.07
P1		-0.16	3.16
P2		-0.10	1.41
P3		-0.52	1.53
P4		0.05	1.23

Conclusions

The infiltration characteristics of the semi-arid alfisols under SAPs are very important to understand the water dynamics in the root zone and its availability to the plants. Besides this, reducing water loss through evaporation and percolation is one of the challenging tasks in semi-arid region. Therefore, super absorbent polymers (SAPs) have been used for drought management and moisture conservation within the root zone in sandy loam soils for improving the productivity in semi-arid regions. The present study indicated that, the application of SAPs has decreased steady state infiltration rate (SIR) in sandy loam soil. The infiltration rates were decreased from 14 to 3.6, 13.6 to 4, 14 to 1.4 and 9.2 to 1.6 cm/hr under 0.25% in P1, P2, P3 and P4 SAPs, respectively. Under 0.75%, the SIR decreased from 11.4 to 2, 11.2 to 0.4, 10.2 to 1 and 8.8 to 1.28 in P1, P2, P3 and P4 SAPs, respectively. The SIR under 1.25% varied from 5.4 to 1.8, 8 to 0.4, 4.6 to 0.6 and 4.8 to 0.8 in P1, P2, P3 and P4 SAPs, respectively. Under 1.75%, the SIR was further reduced by 5.1 to 1.4, 2 to 0.4, 3.9 to 0.5 and 2.6 to 0.76 in P1, P2, P3 and P4 SAPs, respectively. Among all the selected polymers, P3 has maximum (90%) reduction in steady infiltration rate over the entire range of SAP application rates (0.25 to 1.75%). Thus, this study suggested that the polymer P3 can be used as soil amendment in semi-arid alfisols to reduce percolation losses leading to more availability of water for plants in the root zone.

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