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Effect of Different Forms of Super Absorbent Polymers on Soil Physical & Chemical Properties in Orchard field

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***Abstract*—**This research aimed to evaluate the effect of different forms of Super Absorbent Polymers (SAP) on soil physical and chemical properties under orchard field condition. Total area under the experiment was divided into twelve plant pits of size 0.46 m × 0.46 m having the depth of 0.60 m, with three replications and four treatments. The treatments were Control, Polymer Water pad, super absorbent polymers (SAP) in Powder form and super absorbent polymers (SAP) in Crystal form. The size of plant pit was set according to the size of polymer water pad. A plastic polythene sheet at a depth of 0.6 meters was given from all the four sides of pits, to prevent the seepage. Water absorbent polymers in powder as well as in crystal forms were mixed with the soil of pit at the rate of 3g/kg of soil. Lemon plants of one year old were transplanted in pits. The samples of soil were taken for physical and chemical properties, before and after applying the treatments. The results reveal that soil bulk density under SAP (Powder) and SAP (Crystal) treatment was reduced thereby soil porosity increased under both treatments while it was unchanged under control and water pad treatments. The field capacity of soil under both treatments was increased as compared to control and water pad treatment. The pH of soil under all treatments was decreased. EC of soil under water pad and SAP (Powder) was increased while there was a minimum increase in EC of soil under Control and SAP (Crystal) treatment. Under water pad and SAP (Powder) treatments, cations (K & Na) and minerals (Ca + Mg) were accumulated. The SAR and ESP of soil under all SAP treatments were increased as compared with control.

Keywords — Super absorbent polymers, Water saving, Increasing irrigation interval, Increasing crop yield, Increasing soil fertility.

I. INTRODUCTION

Water is essential for sustaining life on the earth. Its consumption by the agriculture sector continues to determine the overall requirements of water. Moreover increasing population approximately 2% per year has increased the water demand. Pakistan is extremely in short of freshwater resources. It is now leading to become a water-stressed country by the year 2035 [1]. Per capita availability of water, which was 5650 m^3 per year in 1951 and 1200 m^3 per year in 2003, is expected to decline further to 1000 m^3 per year in 2026 [2]. Therefore water security is a very critical issue for Pakistan. The rapid increase in water shortage is a challenge to agriculture which currently accounts for over 70% of total water usage. To ensure food security, it is necessary to promote water-saving agriculture by means of an integrated system that includes water efficient irrigation, agronomic water-saving techniques, and appropriate agricultural management [3]. The application of additives to improve water retention has been found to be a simple and effective way of saving water.

In recent years, Super Absorbent Polymers (SAPs) have been intensively studied; they have special properties because of their three-dimensional structure. They are cross-linked macro-molecules with segments of hydrophilic groups, that can absorb and retain liquids, and the absorbed water is difficult to remove even under pressure [4, 5]. Super Absorbent Polymers (also known as hydrogel, water crystals etc) are simply a type of plastic that possesses some unique water absorbing qualities. The presence of sodium or potassium molecules makes this water absorbent polymer able to form bridges between the long hydrocarbon chains. These bridges known as crosslinking enable the polymer to form into a huge single super molecule (desirable for a number of reasons), including its ability to degrade in the environment and breakdown into simpler molecules, and hold significant amounts of water. Super Absorbent

Polymers (SAPs), a group of new water-saving materials and soil conditioners, have been widely adopted in agriculture, but the local farming community is not familiar about their effects on soil physical and chemical properties under alternating dry and wet conditions. The SAPs that are widely used in agriculture are mainly Polyacrylamide and Polyacrylate polymers. Polyacrylates (called in the industry PAC) are used in disposable diapers, sanitary napkins, etc. and are capable of holding a huge amount of water between 600 and 800 times its weight (purity of the water determines this range the more dissolved solids in the water, the less liquid the polymers can hold). Polyacrylates are usually made with sodium and are more environmentally friendly, breaking down first into ammonia salts and then nitrogen and CO2 in about 4 to 6 months. In contrast, polyacrylamides (often known as PAM) absorb only about 300 to 400 times its own weight in water, use a variety of potassium molecules for crosslinking, and take between 5 and 7 years to completely break down.

Application of liquid (water) absorbent polymers (i.e., hydrogels) or superabsorbent polymers (SAPs) such as Polyacrylates cross-linked with polyacrylamides (PAM) can efficiently increase the ability of upper soil profile to hold the water and nutrients for long, which may be available for plant growth and production [6, 7, 8] and decreases the leakage of water, and extract of fertilizer and prevents heavy metals to leach down the soil profile [9].

Amendment of SAP's in soil can yield results such as; (i) decreases bulk density, (ii) escalation in soil aggregation, porosity, aeration and water retention capacity [10, 11, 12, 13, 14], (iii) decreases hydraulic conductivity (saturated) of soil and drainage [15, 16] and (iv) reduces pant sensitivity for salinity and work as a source of cautious release of nutrients, [9, 17, 18, 19]. The analysis showed that, the use of SAP increases soil water content at field capacity and at permanent wilting point, which may lead to a significant increase in available water content in various soils textures used under numerous crops' management [20, 21, 22, 23]. The escalation in plant available water can eliminate abiotic stress (shortage of water for plant survival, high temperature and salinity stress); under climate change conditions. Therefore, between the consecutive irrigations it can enable the soils for producing longer intervals, and improves growth of plants and performance [24, 25, 26, 27, 28, 29, 30].

In lieu of evaluating the performance of SAP's for soil moisture (water) balance, the development of crop, tolerance of abiotic stress and irrigation scheduling management are considered as main trajectories. These factors are additional aspects of performance assessment for discussing the advantages of SAPs'. The addition of a small amount (5 g kg-1 soil) of SAP to soils was very effective in increasing the amount of water retained and extending the first stage of evaporation (i.e., the stage where evaporation is controlled by both external and soil-surface conditions) compared to the quantity of water retained by the soils alone [31].

Water absorbent polymers can be used for two purposes: 1)- to store and hold water to add an extra few days between watering, 2)- to protect your plants from over-watering especially if they are planted in an area that tends to pool water. Water is becoming limiting factor for crop production in many parts of the world, especially developing countries like Pakistan [32]. The excessive use of agro-chemical (fertilizers) results deterioration in groundwater and effects the environmental balance [45] and water absorbent polymers can be used to reduce the application rates of agro-chemicals.

Keeping in view of above arguments, the study was carried out to assess the performance of three different forms of super absorbent polymers on soil physical and chemical properties.

II. METHODOLOGY

The experiment was conducted at the research field of the Faculty of Agricultural Engineering, Sindh Agriculture University Tandojam Pakistan in 2016. Following materials and methods were used in this study.

A. Layout of Experiment

The experiment was laid out in Randomized Complete Block Design with three replications and four treatments. Different pits were made and polymers in different forms were applied in the pits. The details of treatments with replications are as under.

T_0 = Control
T_1 = Water pad
T_2 = SAP (Powder)
T_3 = SAP (Crystal)

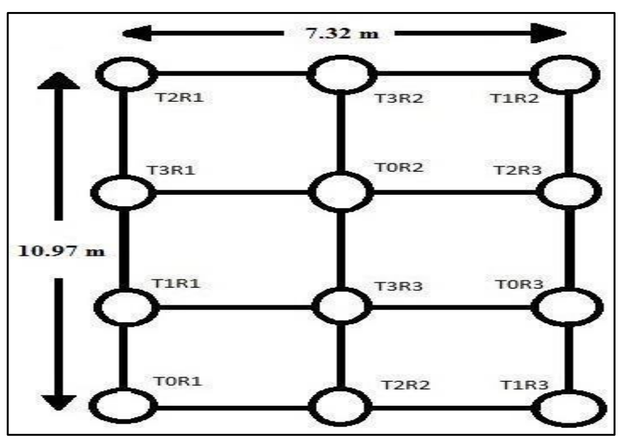

Figure 1. Layout of experimental site showing treatments with replications.

B. Preparation of Land and Plant pits

The experimental land was levelled manually using a spade. Total experimental area of about 80.3 m^2 was divided for twelve plant pits with equal space from all sides. Plant pits were further divided into four groups for required treatments and replications. The size of each plant pit was kept as 0.46 m x 0.46 m and was dug at a depth of 0.6 m. The size of pant pits was set as per the size of polymer water pad.

C. Application of SAP in the pit soil

1) Water pad application in soil

After digging the pits water pads were laid at the bottom of the pit. The polythene plastic sheet at a depth of 0.9 m in the walls of the pit was provided to prevent the seepage. The obtained soil was refilled in the same pit. The plant pit and water pad size were the same, therefore same water pads were used without any additional cutting from any side.

Figure 2. *Polymer Water pad application in pit soil.*

2) SAP (Powder) and SAP (Crystal) application in soil

SAP (Powder) and SAP (Crystal) both are separate treatments, but the mixing ratio of both treatments was same (3gm/kg of soil). The mixing of both forms of SAP with soil was performed manually. The polythene plastic sheets at a depth of 0.9 m were provided from all the four sides of the pit to prevent the seepage. The application rate of both forms of SAP (Powder & Crystal) was applied as suggested by [44].

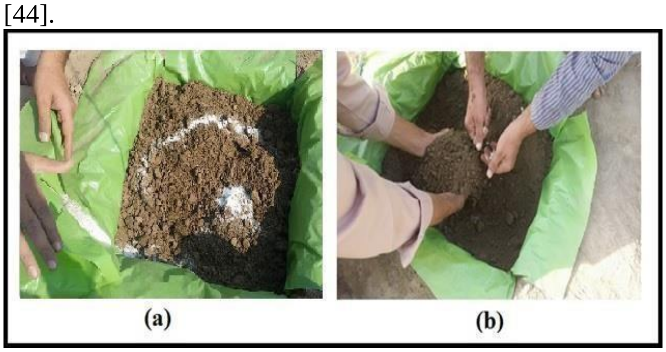

Figure 3. *(a) SAP (Powder) and (b) SAP (Crystal) application in soil.*

D. Quality of irrigation water applied

To determine the quality of irrigation water, the water samples were collected before applying of water to the pits. These samples were analyzed for pH and EC_w with the help of digital pH meter and digital EC meter respectively [33]. The water having E_c of 1.28 ds/m and 7.30 pH was used for irrigation purpose, under all the treatments.

E. Water application method

In order to test the moisture retention capacity of water absorbent polymer amended soil compared with control treatment, the irrigation water with equal volume was applied on first irrigation (as a socking dose) to all the plant pits and further watering was practiced on 50% soil moisture depletion observed for further study period. For all the irrigation water applications, the volumetric method was applied. A container of known volume was used for accurate application of water uniformly [34].

F. Determination of soil physical properties

1) Soil Sampling

To determine soil texture, pH, EC and bulk density of experimental site, the composite soil samples were collected at depth of 0-15, 15-30 and 30-60 cm respectively with the help of soil auger and core sampler and averages were worked out.

2) Soil Texture

Soil texture was determined by Bouyouncos Hydrometer method in the laboratory of Department of Irrigation and Drainage, Faculty of Agricultural Engineering, Sindh Agriculture University Tandojam [35].

3) Dry Bulk Density

The dry bulk density of the soil was determined by taking, composite soil samples using core-sampler of known diameter from each pit of the plant before and after treatment [36].

$$\rho_{bd} = \frac{W_d}{T_v} \qquad (1)$$

Where,

ρ_{bd} = Dry Bulk Density (gm/cm^3)

W_d = Wet weight of soil sample (gm)

T_v = Total Volume of soil (cm^3)

4) Field Capacity

The field capacity of the soil was determined using Viehmeyer and Hendrickson method [37].

5) Soil Porosity

Soil porosity frequently depends upon the bulk density of soil. The porosity of collected soil samples was determined using relationship employed by [36].

$$\eta = \left(1 - \frac{\rho_b}{\rho_p}\right) \times 100 \qquad (2)$$

Where,
η = Soil Porosity (%)
ρ_b = dry bulk density (gm/cm^3)
ρ_p = Soil Particle density (2.65 gm/cm^3)

6) Moisture Content

Moisture content (on the dry weight basis) was determined using the following formula [38].

$$MC = \left(\frac{W_w - W_d}{W_d}\right) \times 100 \qquad (3)$$

Where,
M.C= Moisture Content (%)
W_w = Wet weight of soil (gm)
W_d = Dry weight of soil (gm).

G. Determination of Soil chemical properties

1) pH and EC of Soil

Soil pH and soil EC was determined at 1:3 ratio of soil-water extract with the help of digital pH meter and digital EC meter respectively [39].

2) Soil Potassium (K) and Soil Sodium (Na)

The concentration of soil potassium and soil sodium present in each soil pit was determined using flame photometer. The samples were collected at pre specified depths and they were analyzed accordingly [18].

3) Calcium + Magnesium (Ca + Mg) in Soil

Quantity of Calcium + Magnesium present in each soil pit was determined by EDTA (Ethylene Diamante Tetra Acetic Acid) titration method. For this chemical test, the EDTA, buffer solution, and Erich Rome black T (EBT) indicator were used [11]

4) Sodium Absorption Ratio (SAR)

To determine the sodium absorption ratio, following relationship was used [33].

$$SAR = \frac{N_a}{\sqrt{\frac{(C_a + M_g)}{2}}} \qquad (4)$$

Where,
SAR = Sodium absorption ratio
Na = Sodium
$C_a + M_g$ = Calcium + Magnesium

5) Exchangeable Sodium Percentage (ESP)

Soil ESP and SAR are commonly used to assess soil sodicity. The Exchangeable Sodium Percentage was determined using following empirical formula [40].

$$ESP = \frac{100\,(-0.01475 + 0.0126\,SAR)}{1 + (-0.01475 + 0.0126\,SAR)} \qquad (5)$$

Where,
ESP = Exchangeable sodium percentage
SAR = Sodium absorption ratio

III. RESULTS AND DISCUSSION

Super absorbent polymers (SAP) have been used as water-retaining materials in the agricultural and horticultural fields because when incorporated in the soil, they can retain large quantities of water and nutrients. The stored water and nutrients are released slowly as required by the plant to improve growth under limited water supply [41]. The data analyzed in this study shows that the applied forms of SAP have a remarkable effect on soil physical and chemical properties. The soil characteristics of the experimental field are given in table 1.

Table 1: Soil characteristics of the experimental field.

S. No	Parameters	Soil characteristics
1.	Soil Texture	Silt Loam
2	Dry Bulk Density	1.46 gm cm^{-3}
3	Electrical Conductivity	1.27 dS m^{-1}
4	pH	7.87
5	Field capacity	42 %

A. Effect on Soil Physical Properties

1) Bulk Density & Porosity of Soil

Generally, the soil porosity is considered as opposite of soil bulk density, if one increases the other one will ultimately decrease. The bulk density of soil was decreased by 10 and 11.5 % and soil porosity was increased by 10.20 and 12.60 % with the amendment of powder and crystal forms of super absorbent polymers respectively, as shown in table 2 & 3. However, there was no any significant change found in soil bulk density and soil porosity under control and polymer water pad treatment. As water pad was laid at the bottom of pit which provides a barrier to water movement below the pit. The soil profile above the pad was of the same characteristics as that of control treatment. The results of soil bulk density and porosity are in quiet agreement with the results discussed by [10, 12, 13, 14, 29].

Table 2: Soil Bulk density before and after the experiment.

S. No	Treatment	Bulk Density (gm/cm^3)	
		Before	After
1	Control	1.52	1.49
2	Water Pad	1.42	1.42
3	SAP (Powder)	1.42	1.28
4	SAP (Crystal)	1.47	1.3

Table 3: Porosity of soil before and after the experiment.

S. No	Treatment	Porosity (%)	
		Before	After
1	Control	42.64	42.77
2	Water Pad	46.42	46.42
3	SAP (Powder)	46.42	51.70
4	SAP (Crystal)	44.53	50.94

2) Soil Moisture Content

After applying of first water (socking dose) to the soil under each treatment, the 50% of soil moisture depletion was observed on 15th, 15th, 12th and 7th day under powder polymers, water pad polymers, crystal polymers, and control treatment respectively, as shown in table 4. Therefore, the number of irrigation water application is decreased under each form of water absorbent polymer treatment as compared to the control one. The results further shows that, by the application of super absorbent polymers (SAP) more water can be saved because of its own liquid/water absorbent property. The analysis of moisture holding capacity shows close fit agreement with [6, 8, 42].

Table 4. Date-wise Moisture Content (%) in the soil under all the treatments.

INTERVAL	M.C (%) under Control	M.C (%) under Water Pad	M.C (%) under SAP Powder	M.C (%) under SAP Crystal
16th - Jan	23.63	26.73	37.06	23.60
18th - Jan	19.03	24.30	28.13	22.90
20th - Jan	1ST irrigation	23.20	25.38	21.17
22th - Jan	24.23	22.23	23.63	19.07
24th - Jan	22.63	21.63	21.36	1ST irrigation
26th - Jan	20.18	21.01	19.90	26.34
28th - Jan	2ND irrigation	1ST irrigation	1ST irrigation	25.66
30th - Jan	24.13	26.91	29.34	24.75
1st - Feb	22.41	23.81	26.18	23.82
3rd - Feb	20.05	21.33	23.69	20.93
5th - Feb	3RD irrigation	19.24	21.93	2ND irrigation
7th - Feb	24.78	2ND irrigation	18.28	25.32
9th - Feb	23.07	27.37	2ND irrigation	24.93
11th - Feb	21.68	25.43	31.23	23.83
13th - Feb	19.83	23.78	28.32	23.22
15th - Feb	4TH irrigation	21.58	26.53	22.18

B. Effect on Soil Chemical Properties

1) pH and EC of soil

Soil pH values were found with a decreasing trend. The soil pH was reduced by 3.8, 4.7. 4.5, and 3.6 % respectively under control, water pad polymer, powder polymer and crystal polymer treatments, respectively. The reduced pH might have accelerated the release of soil inorganic salts and minerals which would have resulted in increased EC values. The EC of soil showed increasing trend and the maximum EC was observed under water pad polymers followed by powder polymer treatment. The reason behind this increase is that the slat concentration (EC of irrigation water) is continuously being accumulated at the bottom in water pad treatment and due to cross-linkage chain under powder polymer treatment the leaching is reduced. Whereas, there was minimum difference found for soil EC, under control and crystal polymer treatments, as shown in Table 5. The results of pH and EC are resembling with the results concluded by [11, 43].

Table 5. pH & EC of soil before and after the treatment.

S.No	Treatment	pH		EC (ds/m)	
		Before	After	Before	After
1	Control	7.84	7.54	1.3	1.46
2	Water Pad	7.87	7.50	1.28	3.64
3	SAP Powder	7.78	7.43	1.29	2.58
4	SAP Crystal	7.87	7.59	1.27	1.36

2) Soil Potassium (K) content

With regard to soil potassium (K) content, the concentration of K was increased by 82.20, 78.75, and 40.21 % under Water pad polymer, Crystal polymer and Powder polymer treatments, respectively. Obtained results were in comparison with control treatment, as illustrated in Table 6. However, the results obtained in this experiment are not resembling by any means with the experiment performed by [11], according to their results, with the application of 0.3% of SAP the K values were increased by 3.4 to 16 %.

Table 6. The potassium (K) present in the soil after application of SAP.

S. No	Treatment	K (Meq/l)
1	Control	0.58
2	Water Pad	3.26
3	SAP (Powder)	0.97
4	SAP (Crystal)	2.73

3) Soil Sodium (Na) content

The results of soil potassium closely matches with results shared by [18 and 19] Sodium present in the soil depends upon the available soil sodium content and accumulation of salts after applying of irrigation water. Figure 4 shows that the soil sodium content is increased by 70.50, 43.70 and 46.59 % under Water pad, SAP (Powder) and SAP (Crystal) treatment respectively, when compared with Control treatment. This increase in sodium (Na) at the higher percentage level is due to the accumulation of salts by irrigation water. The results shows close fit agreement with [9, 17].

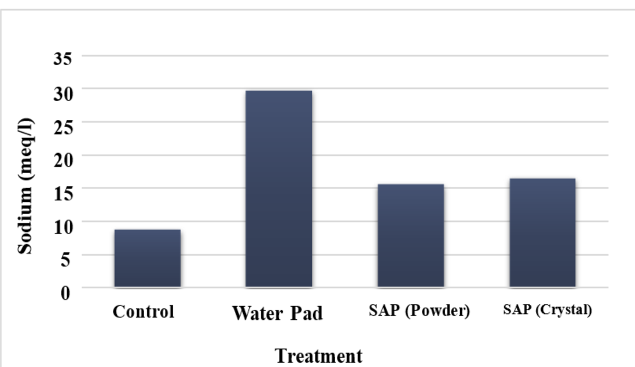

Figure 4. The Sodium (Na) present in the soil after the SAP application.

4) Soil minerals (Ca + Mg)

The availability of required soil minerals concentration (Ca + Mg) can help the plants to increase their growth. The results of the present study shows that the calcium + magnesium content present in the pit soil under the application of Water pad polymer and Powder polymer is increased by 83.53 and 53.15 %, respectively. The results are in quiet agreement with [9, 17 and 18]. The maximum increasing percentage of soil minerals under water pad treatment is because the leaching resistance and due to the cross-linkage chain under powder form of polymers the amount of Ca + Mg is also showing a profound increase, as shown in Table 7.

Table 7. Calcium + Magnesium (Ca+Mg) present in the pit soil after application of SAP.

S. No	Treatment	Ca + Mg (mg/l)
01	Control	5.2
02	Water Pad	31.57
03	SAP (Powder)	11.10
04	SAP (Crystal)	2.07

5) Sodium Absorption Ratio

In order to determine the Sodium Absorption Ratio (SAR) the soil samples were collected at the end of experiment from each soil pit. The results indicate that with the application of Crystal, Powder and Water pad polymers the SAR was increased by 66 %, 17.82% and 27.27% respectively, compared with control treatment. Under the control treatment it was observed as 5.44 (see Table 8). The results of SAR as a relation with ESP resembling with the results of study carried out by [31].

Table 8. SAR of the soil under SAP treatments after the experiment.

S. No	Treatment	SAR
1	Control	5.44
2	Water Pad	7.48
3	SAP (Powder)	6.62
4	SAP (Crystal)	16.08

6) Exchangeable Sodium Percentage

In contest of Exchangeable Sodium Percentage (ESP), it was observed with greater increase only in Crystal polymer application. The ESP was increased by 67.43 %, 30.26 % and 20 % under Crystal polymer, water pads and powder polymers, respectively. The results indicates that the minimum increase in ESP is observed under the soils which are amended with polymers in powder form (see Figure 5). The results of ESP are showing close fit agreement with [31].

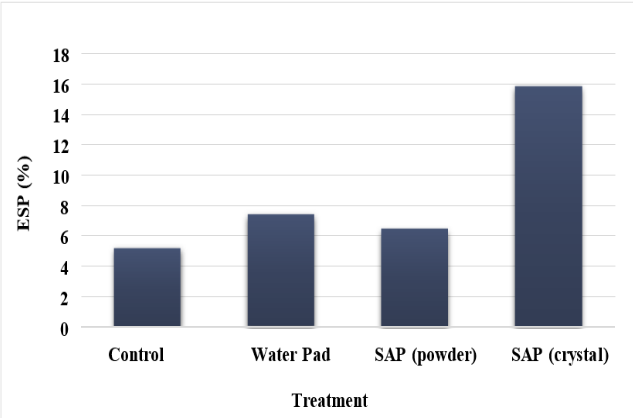

Figure 5. ESP of the soil under SAP treatments after the experiment.

IV. CONCLUSION AND FUTURE SCOPE

There is tremendous effect of all types of Super Absorbent Polymers on physical as well as on chemical properties of soil. On the basis of the above results, the application of super absorbent polymers is hereby recommended for the soils having poor physical and chemical properties. The increased irrigation interval under tested forms of SAP indicates a great satisfaction of moisture holding capacity of soil. Thus, irrigation water could be saved using all the tested forms of Super Absorbent Polymers. High accumulation of soil cations and minerals reflects that, the fertilizer extract will also be accumulated therefore fertilizer application can be reduced or minimized with the incorporation of super absorbent polymers in the soil. It is inferred on the basis of results, the water pad polymers gave the best results among used forms of SAP.

In future, studies should be conducted to investigate the effects of super absorbent polymers on yield and fertilizer saving under traditional farming methods of seasonal crops and vegetables. The application rate of SAP in Powder and Crystal forms, may be tested at different levels for optimum results.

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