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Water Absorption by Synthetic Polymer (Aquasorb) and its Effect on Soil Properties and Tomato Yield

RIFAT HAYAT[1] AND SAFDAR ALI
Department of Soil Science, and Soil and Water Conservation, University of Arid Agriculture, Rawalpindi–Pakistan
[1]Corresponding author's e-mail: mriffathayyat@hotmail.com

ABSTRACT

In arid and semi-arid regions, efficient utilization of available water necessitates the adaptation of appropriate water management practices. Soil conditioners have been reported to be effective tools in increasing water holding capacity, reducing infiltration rate and cumulative evaporation, and improving water conservation of sandy soils. In view of the characteristics of the hydro-gels/polymers and peculiar problems of rainfed areas, laboratory and green house studies were carried out to observe the absorption of water by synthetic polymer (Aquasorb) and to investigate the effect of its application on moisture content, nutrient supply, physico-chemical properties of sandy loam soil and yield parameters of tomato crop. In the laboratory, a weighed quantity (1g) of Aquasorb was placed in excessive quantity of water in 1000 ml beaker and the polymer (Aquasorb) were weighed after 30, 60, 90, 120, 150, 180 and 210 minutes to determine the rate of water absorption. Aquasorb absorbs water slowly and water absorption increases with time that varied from 83-219 times their weight during 30-210 minutes. Under green house experiment seven concentrations (0, 0.25, 0.50, 0.75, 1.00, 1.25 and 1.50%) of polymer (Aquasorb) were used. Ten kg of soil was filled in each pot. Polymer was thoroughly mixed into the soil. All the treatments were irrigated when the plants at control showed sign of wilting. It was noted that moisture content in the polymer treated soil increased from 30 to 850%. The addition of polymer induced substantial changes in the physical properties of the soil. Saturation percentage increased significantly and the response was 17% better than control. Particle density and bulk density were reduced due to the application of polymer. There was 8% reduction in particle density of soil, whereas reduction in bulk density was 4 to 80%. The pH and electrical conductivity of the soil remained unaffected. Vegetative growth and fruit production were significantly increased, but there was no significant variation in N P K contents in the plants.

Key Words: Polymer; Aquasorb; Moisture; Bulk density; Tomato yield

INTRODUCTION

Rainfed agriculture is a highly risky business. Uncertain precipitation is a major constraint to crop production especially when it occurs at an unexpected time and problems become aggravated if dry conditions prevail for a longer time. Crop damage from dry weather can be reduced by supplemental irrigation of harvested rainwater or conservation of as much rainwater in the soil as possible. Suitable conservation techniques help in the interval and reduction in the frequency of irrigation. Such practices can ensure crop survival and increased production (Chaudhry, 1992). Crop production is mainly dependent on ecological and soil conditions. Moisture stress is a major constraint for crop growth in arid and semi arid regions, as the precipitation is low and uncertain in these areas. Efficient utilization of meager soil and water resources necessitates the adaptation of appropriate water management techniques. Soil conditioners have been reported to be effective tools in increasing water holding capacity, reducing infiltration rate and cumulative evaporation and improving water conservation of sandy soils (Al-Omran *et al.,* 1987). Wallace and Wallace (1986) reported that the polymers improved the soil characteristics. It was further revealed that low level of polymer application caused very little improvement compared with high one. Fruit quality was also improved by the application of polymers to growing media due to the reduced impact of water stress during the growing cycle (Johnson & Piper, 1997). Anter and DeBoodt (1976) stated that polymers encouraged the uptake of nutrient elements by plants.

The use of polymers is not new in agriculture. These were first used in soil conservation in the 1950s, when non-cross-linked acrylamides, vinyl alcohols and liquid plastic, and rubber compounds were introduced for stabilization of soil aggregates for control of water/wind erosion (Gardner, 1986; Helalia & Letey, 1988). This development was followed from the 1960s introduction of the cross-linked polymers in which the polymer matrix was chemically engineered to permit absorption and release of large quantities of water. These products are synthetic chemicals and have been advocated as aids to plant production under arid conditions where water resources are limiting (Johnson, 1988). The polymers can be synthesized that are either non-ionic, cationic, or anionic. Some of these being water soluble may be applied with irrigation water (Helalia & Latey, 1988).

Polyacrylamide (PAM) is a long chain synthetic polymer that acts as a strengthening agent, binding soil particles together and consequently these larger and heavier particles cannot be removed easily by water. Polyacrylamide are being marketed under different trade names like: Terrasorb, Hydrosource, Hydro-Mulch, Water Crystals, PAM, Copolymer, Moist Soil, Aquasorb, Agrosoke etc. All these products are polymers, but not all polyacrylamide are alike. Polyacrylamide was developed in the 60's to grow plants in the desert and has been refined to last longer and absorb water at higher rates over a period of time. Polymers as soil additives have recently been introduced in the market with great success. These polymers are sold under the names of "Smart Soil" and "Moist Soil" to hold water (20 times its weight), but polyacryamide (400 times) is now used for this purpose. The interaction of the polymers depends on both the properties of polymer and properties of soil. It is effective in stabilizing soil aggregates, reducing soil erosion and increasing water infiltration and also indirectly profoundly affects crop growth and yield (Seybold., 1994). Polyacrylamides are useful where water is scarce or expensive and where drought is a significant hazard in crop production. However, different types of polymers vary widely in their capacities to absorb water and release. Scanning electron microscopy showed that high performance products have a cellular structure in the expanded conditions with plant available moisture stored within this enclosed vacuoles and within the polymer frame work. The bridges that comprise the structure of the gel control water release under dry conditions and optimize recovery of the stored water by plants (Johnson & Veltkamp, 1985). Hence in view of the characteristics of the hydrogels/polymers and peculiar problems of rainfed areas, laboratory and green house studies were undertaken to observe the absorption of water by polymer (Aquasorb) and to evaluate the effects of polymers on soil physical characteristics and crop behavior with the objectives, to estimate moisture content in the soil over a period of time in the polymer treated soil, to determine nutrient contents in the tomato crop as a result of polymer application and to observe plant characteristics and tomato yield response in the polymer amended soil.

MATERIALS AND METHODS

Laboratory and green house studies were carried out at University of Arid Agriculture, Rawalpindi on coarse textured soil (sandy loam) to observe the absorption of water by synthetic polymer (Aquasorb) and its effect on soil properties and tomato production.

Laboratory studies to observe the absorption of water. A weighed quantity (1g) of Aquasorb was placed in excessive quantity of water in 1000 mL beaker and the polymer (Aquasorb) were weighed after 30, 60, 90, 120, 150, 180 and 210 minutes to observe the rate of water absorption.

Table I. Physical and chemical characteristics of soil used for the study

Characteristic	Values
Texture	Sandy soil
Particle density (Mg m^{-3})	2.70
Bulk density (Mg m^{-3})	1.59
Saturation percentage (%)	22.00
pHs	7.60
ECe (dSm^{-1})	0.30
Nitrate – Nitrogen (mg kg^{-1})	6.00
Olsen P (mg kg^{-1})	3.00
Potassium (mg kg^{-1})	80.00
Total organic carbon (TOC)%	0.3.00

Green house experiment. Soil samples collected from farmer's field of district Attock were air-dried, thoroughly mixed and passed through 2-mm sieve. Physical and chemical characteristics of the soil are shown in Table 1. Ten kg of soil was filled in each pot. Polymer was thoroughly mixed into the soil with the following treatments:

T_1 Control
T_2 0.25% Aquasorb (2.5g kg^{-1})
T_3 0.50% Aquasorb (5.0 g kg^{-1})
T_4 0.75% Aquasorb (7.5 g kg^{-1}
T_5 1.00% Aquasorb (10.0 g kg^{-1})
T_6 1.25% Aquasorb (12.5 g kg^{-1})
T_7 1.50% Aquasorb (15.0 g kg^{-1})

There were three replications of each treatment. NPK fertilizers were applied @ 100-80-40 kg ha^{-1} as urea, diammonium phosphate (DAP) and potassium sulphate (K_2SO_4). Pots were saturated with tap water before sowing/transplanting the seedling. Two seedlings of tomato crop, var. Money Maker were potted in each pot on 14-06-2000. Subsequent irrigations were applied only when the plants showed signs of wilting in the control treatments. Soil samples were periodically collected before subsequent irrigations with a tube soil sampler for moisture estimation. Fruit yield and biomass were also recorded. Soil samples were again collected which were analyzed for nitrate-N, total organic carbon (TOC), phosphorus and potassium, bulk density, particle density and saturation percentage. NPK of plant samples were also determined. Data were statistically analysed for variance of various factors and means were compared by applying Least Significant Difference test at 5%% level of probability (Steel & Torrie, 1980).

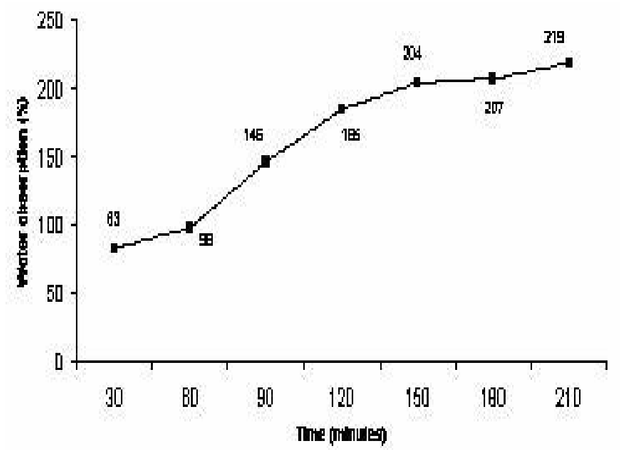
RESULTS AND DISCUSSION

Laboratory studies to observe the absorption of water. Average rate of absorption of water by Aquasorb after 30, 60, 90, 120, 150, 180 and 210 minutes revealed that the water absorption by Aquasorb increased in a time course manner. The average absorption of water by Aquasorb after 30, 60, 90, 120, 150, 180 and 210 minutes was found to be 83, 98, 146, 185, 204, 207 and 219 times its weight respectively (Fig. 1). It has been reported that Aquasorb takes 20 minutes to achieve 50% absorption and 120 minutes for 100% absorption. The range of water absorption has been reported to vary from 30-500 litres per kg of dry polymers and can remain effective for 4-5 years, and water exchange between the soil and the polymer is reversible. Chaudhry *et al.* (1994) revealed that average water absorption by Aquasorb after 30, 60, 90 and 120 minutes was 65, 94, 110 and 130 times its weight. Aslam and Shahid (1992) found that the potential water retention by Aquasorb were 21.5% and constant expansion rate achieved after 240 minutes. The effective retention by Aquasorb is 49 g of water per g of polymer. The effective retention is 50% of the potential retention for Aquasorb.

Green House Experiment

Moisture. Data of moisture content of sandy loam soil are given in Table II. It is evident from the observations recorded on June 17, 2000 that highest soil moisture content (30.05%) was observed in 1.5% Aquasorb treated soil which was followed by 1.25 (26.99%) and 1% (26.67%) Aquasorb treatments, respectively. There was insignificant variation in the moisture content of the soil treated with 1 and 1.25% Aquasorb. However, the values of 1.5% and 1.25% Aquasorb treated soil differed significantly. Lowest amount of moisture content was observed in the untreated soil. It was further revealed that there were significant differences amongst all levels of Aquasorb. Moisture content data recorded on July 8, 2000 revealed that highest amount of moisture was observed in 1.5% Aquasorb (19.74%) treated soil followed by 1.25% (15.95%) and 1.00% Aquasorb (14.94%) and they differed significantly. Lowest moisture content was observed in the untreated soil which was significantly lower than all the other values. Almost same behaviour was observed at different time intervals. Chaudhry (1995) reported that mean moisture values were higher in polymer treated soil as compared with those of organic matter and control. Al-Omran *et al.*, (1987) reported that the gel helped in reducing evaporative water losses and consequently caused moisture retention in the soil.

Fig. 1. Absorption of water by aquasorb at different time interval



Saturation percentage. It was revealed from the saturation

Table II. Effect of various treatments of Aquasorb on moisture retention (%) of soil (sandy loam) at different time intervals

Treatment	17.6.00	23.6.00	30.6.00	8.7.00	18.7.00	2.8.00	9.8.00	24.8.00	4.9.00	16.9.00	Means
T_1 (Control)	3.09 f	2.92c	3.08 e	2.84 g	3.94 e	2.65 g	3.52 d	1.03 e	3.28 e	2.30 e	2.68
T_2(0.25%Aquasorb)	6.59e	4.55 c	4.09 d	4.63 f	4.42 e	6.22 f	4.20 d	1.88	5.88 e	4.08 f	2.65
T_3 (0.50% Aquasorb)	16.98 d	13.88 b	12.03 c	12.13 e	10.37 d	13.87e	13.15c	5.98	6.95 d	5.19 e	2.65
T_4 (0.75% Aquasorb)	20.52 c	14.72 b	12.23 bc	13.25 d	12.02 d	14.59 d	13.87 bc	12.28	7.18 c	14.60 d	10.53
T_5 (1.00% Aquasorb)	26.67 b	15.41 b	12.83 bc	14.94 d	15.27 c	15.12 c	14.69 b	19.57	9.02 b	18.70c	13.53
T_6 (1.25% Aquasorb)	26.99 b	20.44 a	13.17 b	15.95 b	15.67 b	15.98 v	19.30 a	23.03	11.14 ab	24.69 b	14.35
T_7 (1.50% Aquasorb)	30.05 a	21.59 a	14.80 a	19.74	16.91 a	17.82 a	19.66 a	24.40	18.89 a	26.66 a	16.17
LSD	2.961	1.779	0.9071	0.7569	0.8569	0.2923	0.8476	3.489	23032	0.3732	21.05

Treatments with same letters are non-significant and treatments bearing different letters are significantly different at 5 percent level of probability.

Table III. Effect of various treatments of Aquasorb on some physico-chemical characteristics of sandy loam soil after the harvest of tomato crop

Treatments	Saturation percentage	Bulk density (gcm^{-3})	Particle density (gcm^{-3})	pHs	ECe (dSm^{-1})
T_1 (Control)	21.64 b	1.59 a	2.70 a	7.60 NS	0.90 a
T_2 (0.25% Aquasorb)	22.20 b	1.53 ab	2.65 ab	7.70	0.80 b
T_3 (0.50% Aquasorb)	22.41 b	1.46 b	2.61b	7.60	0.70 c
T_4 (0.75% Aquasorb)	22.74 b	1.27 c	2.60 b	7.60	0.60 d
T_5 (1.00% Aquasorb)	24.32 a	1.13 d	2.52 c	7.53	0.70 c
T_6 (1.25% Aquasorb)	24.56 a	1.10 e	2.48 cd	7.63	0.70 c
T_7 (1.50% Aquasorb)	25.42 a	0.88 f	2.46 d	7.60	0.70 c
LSD (0.05)	1.319	0.07956	0.05625	NS	0.056

Treatments with same letters are non-significant and treatments bearing different letters are significantly different at 5 percent level of probability.

percentage values of sandy loam soil that due to various treatments, there was an increase in the saturation percentage by the application of Aquasorb. Highest value of saturation percentage (25.42%) was found in soil which received 1.5% application of Aquasorb. These were significantly higher when compared with other treatments. Almost all the soils treated with various levels of Aquasorb showed higher values in comparison to untreated soil (21.64%) (Table III). Polymer application might have enhanced the saturation percentage because of their increased moisture retention. Al-Omran *et al.,* (1987) were of the view that the gel conditioners enhanced the water holding capacity of the soil.

Bulk density. Highest value of bulk density (1.59 Mg m^{-3}) was observed in the untreated soil, which was followed by 0.25% Aquasorb (1.53 Mg m^{-3}). It is evident from the data that bulk density values observed by untreated soil and those treated with 0.25, 0.50, 1.00, 1.25, and 1.5% Aquasorb application further lowered the bulk density which were significantly different compared with the aforementioned values (Table III). The swelling and shrinkage results in higher soil and causes a reduction in the hardness of surface. Terry and Nelson (1986) revealed that bulk density of PAM treated soil was reduced. Wallace and Wallace (1986) elucidated that the polymers improved the soil characteristics. It was further revealed that low levels of polymer application caused very little improvement compared with high ones.

Particle density. Highest value (2.70 Mg m^{-3}) of particle density was found in the untreated soil, whereas lowest value (2.46 Mg m^{-3}) was observed where 1.50% Aquasorb was applied. The value of particle density at 0.25, 0.50 and 0.75% level of Aquasorb were not significant (2.65, 2.61 and 2.60 Mg m^{-3}). The lowest value of particle density at 1.5% level of Aquasorb was significantly lower when compared with that of untreated soil (Table III). The reduction in the particle densities of the Aquasorb treated soils is plausibly due to the biodegradation of this material. Dilkova (1975) observed a similar reduction in particle density of different soils and consequently a marked increase in the air filled pores was noticed. Similar results were illustrated by Gabriels *et al.* (1975).

pH and electrical conductivity of soil. The perusal of the data indicates that the differences in pH of the soil amongst all the treatments were not significant. The electrical conductivity values of the soil observed after the harvest of the crop also revealed that these values did not vary significantly, though there were some differences amongst various treatments (Table III).

Nutrient contents in the soil. The data of nitrate-N, phosphorus, potassium and total organic carbon (TOC) of sandy loam soil revealed that the value of all levels of Aquasorb were mutually non-significant (Table IV). No evidence is so far available regarding the direct interaction of the polymers and nutrients. But it may be due to increased moisture retention that enhanced the nutritional supply. However, the effects of polymers on the nutrient content in the soil after the harvest of the crop were not so conspicuous (Chaudhry, 1992).

Table IV. Effect of various treatments of Aquasorb on nutrient contents of the sandy loam soil after the harvest of tomato crop

Treatments	NO_3-N (mg kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	*TOC (%)
T_1 (Control)	5.27 NS	2.17 NS	81.67 de	0.39 NS
T_2(0.25%Aquasorb)	5.75	2.33	86.67 bd	0.43
T_3 (0.50% Aquasorb)	4.93	2.50	85.00 cd	0.36
T_4 (0.75% Aquasorb)	4.49	3.00	90.00 ab	0.41
T_5 (1.00% Aquasorb)	4.90	2.30	80.00 e	0.47
T_6 (1.25% Aquasorb)	4.99	2.67	91.67 a	0.40
T_7 (1.50% Aquasorb)	5.60	2.50	85.00 cd	0.37
LSD (0.05)	NS	NS	4.552	NS

*TOC = Total organic carbon

Treatments with same letters are non-significant and treatments bearing different letters are significantly different at 5 percent level probability.

Effect of Polymer (Aquasorb) on Crop Characteristics

Number of leaves and branches per plant. Number of leaves per plant were highest in sandy loam soil receiving 1.25% Aquasorb (348) followed by 1.5% Aquasorb (247) (Table V). It was observed that number of branches per plant was highest in soil receiving 1.25% Aquasorb (20) followed by 1.5% Aquasorb (17) (Table V). Application of polymers in addition to improving the aeration and water storage capacity enhanced the moisture and nutritional supply. Seogkyun *et al.* (1998) revealed that early growth and vegetative production of cabbage in K-CMC a natural polymer derivative and polyacrylamide treatments were higher than the control. Up to 0.3% polymer concentration resulted in a significant increase in vegetative growth. Johnson (1984) stated that the use of gel forming synthetic polymers as aids to water retention in sandy soils is an important development to assist plant growth in arid regions.

Fresh and dry weight of plants. The data pertaining to fresh weight of plants indicated that maximum weight (90.96 g) was observed in soil treated with 1.25% Aquasorb treatment and minimum fresh weight (12 g) was observed in the control. The weight of the plants growing in 1.25 and 1.50% Aquasorb were significantly higher as compared to those growing in untreated soil, whereas the treatments did not show significant variation (Table V). Rigas *et al.,* (1999) elucidated that water swelling polymer increased biomass of sunflower grown on a sandy soil. The greatest vegetative growth, expressed as leaf area and shoot fresh and dry weight, was observed at 0.3 and 0.4% hydrophilic polymer.

Fruit yield. Maximum fruit yield (497.7 g) was observed with 1.25% Aquasorb application which was significantly higher than all other levels of Aquasorb and minimum fruit yield was observed in control treatment (87.92) (Table V). Addition of polymers to growing media had beneficial effects on shoot dry weight and fruit production. Fruit

Table V. Effect of various treatments of Aquasorb on yield and yield components of tomato crop

Treatments	No. of leaves per plant	No. of branches per plant	Fresh weight per plant (g)	Dry weight per plant (g)	Fruit yield per plant (g)
T_1 (Control)	84.67 e	10.00 NS	12.40 e	6.14 NS	87.92 d
T_2 (0.25% Aquasorb)	110.0 e	12.33	36.51 d	6.59	180.2 d
T_3 (0.50% Aquasorb)	303.3 b	15.67	35.85 d	7.19	378.4 b
T_4 (0.75% Aquasorb)	200.0 d	16.00	44.64 cd	8.35	262.2 c
T_5 (1.00% Aquasorb)	234.3 cd	16.00	50.0 c	9.95	255.1 c
T_6 (1.25% Aquasorb)	348.3 a	20.00	90.96 a	14.95	497.7 a
T_7 (1.50% Aquasorb)	246.7 c	17.00	80.15 b	12.54	442.3 ab
LSD (0.05)	44.15	NS	NS	NS	115.9

Treatments with same letters are non-significant and treatments bearing different letters are significantly different at 5 percent level probability.

quality was also improved by the application of polymers to growing media due to the reduced impact of water stress during the growing cycle (Johnson & Piper, 1997).

Nutrient contents in the plant. The data showed that the differences in N, P and K values of plants were non-significant. P contents of plants receiving 0.25% Aquasorb (2.15%) was significantly higher as compared to those receiving 1.25 (1.02%) and 1.50% Aquasorb (1.27%). The differences in P values of the plants receiving others treatments were non-significant (Table VI). Though there were slight differences amongst the nutrient contents in the plant grown in sandy loam soil, statistical analysis did not reveal significant variation. The nutrient contents in the plants did not reveal any specific trend. Wallace (1986) found no relationships regarding the effects of polymers on nutrient uptake and crop yield. However, Anter and DeBoodt (1976) stated that polymers promote the nutrients uptake by the plant roots.

Due to high cost, it may not be practical to apply the polymers to ordinary field crops but it may further be tested on horticultural crops especially vegetables when grown under controlled conditions and in nurseries because these significantly reduce the water requirements.

Table VI. Effect of various level of aquasorb on N, P and K content in tomato plant

Treatments	N (%)	P (%)	K (%)
T_1 (Control)	1.28 NS	1.77 ab	1.73 NS
T_2 (0.25% Aquasorb)	2.18	2.15 a	3.16
T_3 (0.50% Aquasorb)	2.13	1.65 ab	3.28
T_4 (0.75% Aquasorb)	1.62	1.55 ab	2.07
T_5 (1.00% Aquasorb)	2.05	1.67 ab	3.36
T_6 (1.25% Aquasorb)	2.00	1.02 b	2.80
T_7 (1.50% Aquasorb)	1.53	1.27 b	2.39
LSD (0.05)	NS	0.6981	NS

Treatments with same letters are non-significant and treatments bearing different letters are significantly different at 5 percent level probability.

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