The improvement of soil water holding capacity, infiltration rate and aggregate stability with different soil conditioners

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Abstract

Water resources in arid and semi-arid areas are scarce due to the low rainfall and high evaporation. Therefore the agricultural water management and soil water conservation strategies has crucial important in this conditions. The improvement of water holding capacity, infiltration rate and aggregate stability are main factors to prevent water and soil loses. This subject has gained important within the agricultural and environmental researcher, and different studies have been conducted a variety of natural and synthetic soil conditioners have been used for this aim. This study makes a widely reviewing about improving soil properties to more effective water management with soil containers. Secondly the objective of this study was to determine the effects of polyacrylamide (PAM), straw mulches (SM), and paper pellets (PP) on water holding capacity (WHC), infiltration rate (IR) and aggregate stability (AS) of soil. Treatments were the application of PAM (10 $mg.L^{-1}$), SM (1.25 and 2.5 $kg.m^{-2}$), and waste PP mulching (1.25 and 2.5 $kg.m^{-2}$). The study results showed that each treatment had effect on especially initial IR. PAM application was little effective on infiltration, whereas it was more effective on AS than the other conditioners. SM and PP applications increased AS depending upon organic matter content in soil. PAM application at given dosages had no significant effect on water holding capacity. However, it can be inferred that other mulching applications had positive effect on field capacity, thereby available water content depending upon mulching rate. However, it is known that the effect of PAM is observed especially in only irrigation with the PAM application and it is not permanently for soil amendment. Therefore, using SM and PP is more appropriate because of their low costs and more persistent effects and evaluation of wastes.
Keywords: Soil water holding capacity, Polyacrylamide , mulching

Introduction

The studies of improving infiltration, aggregate stabi ity (AS) and water holding capacity (WHC) have gained important within the agricultural and environmental researcher. Recently, a number of studies have been conducted on t subject and a variety of natural and synthetic soil conditioners have been used for this aim. The researchers focused on the subject reported that tilled soils with weak structure were reclaimed and aggregation was improved by applying little amount of synthetic water-soluble polymers, which are water to soils, as a result, water movement and aeration increased significantly (Brady & Weil, 2002).

Infiltration rate (IR) is critical for designing an efficient irrigation system and many soil physics studies and depends on the water depth or intensity and duration of the rainfall, slope of the field, nature of the soil surfaces and structure and aggregate properties of the soil. Favourable soil structure and high AS are important for reducing erodibility, improving soil fertility, increasing agronomic productivity, enhancing porosity, and infiltration (Bronick, 2005). AS is used as an indicator of soil structure (S et al., 2000). Aggregation results from the rearrangement of particles, flocculation and cementation (Duiker et al., 2003). It is known that soil physical properties such as good soil structure, stable aggregation, high water retention capacity, good aeration are mostly related to soil organic matter content. The soil organic matter bonds agent between primary and secondary mineral particles to enhanced amount, size and stability of aggregates and orbs water agent it enhances water acceptance and availability and, hence, on infiltration and percolation (Sarah 2006). The complex dynamics of aggregation are the result of the of many factors including the environment, soil management factors, plant influences and soil properties such as mineral composition, texture, SOC concentration, pedogenic processes, microbial activities, exchangeable ions, nutrient reserves, and moisture ava lability (Kay, 1998).

Polyacrylamide (PAM) used in irrigation practices improves IR, AS and reduces erosion. This increases the quality of tail water in irrigation applications, hence, decreases the concentrations of nitrogen, phosphorus, and pesticide irrigation water. Sojka & Entry (2000) observed that PAM application reduced total bacterial and microbial movement compared to the control treatments. Zhang & Miller (1996) investigated the effect of PAM application on infiltration and erosion in furrow irrigation. The results showed that 15 and 30 $kg.ha^{-1}$ PAM application produced similar results and infiltrat increased approximately 50% whereas sediment transport decreased 79%. Lentz et al., (2001) stated that furrow irrigation method had advantages of commonly used and cost and energy requirements, whereas more runoff, erosion, and deep percolation were its some disadvantages. In the case of PAM application; sediment transport, total phosphorus movement, and chemical oxygen demand decreased in significant level. Francisco and Ricard (2000) investigated two different applications: one for continuous 1 mg L^{-1} PAM application during irrigation and the other for 10 $mg.L^{-1}$ PAM application during the advanced time. The continuous application was found more effectively than the other applications. Trankel et al., (1995) studied the effect of PAM application and mulching on sediment transport and infiltration in silty loam soil. The results showed that in both applications reduced sediment tran ort. While no effect of PAM application was observed on infiltration, mulching and mulching + PAM application increased infiltration.

Despite the many materials as soil conditioners, their widespread application on arable lands has been limited, primarily because of economic considerations. With new technological advances and the identification of chemicals that can applied at low, cost-effective concentrations, interest has been renewed. One such soil conditioner is Agri-SC (manufactured by Four Star Services, Bluffton, IN, USA), and it has been found to decrease the erodibility of a sandy loam (Fullen et al., 1993 and 1995).

The effectiveness of sodium polyacrylate to increase soil water retention and to enhance growth of wheat under water deficit was evaluated by D. Geesing & U. Schmidhalter 2004. Water-holding capacity of the soils was considerably increased only when the soil was amended with the polymer at a rate >3 gL.

Rajor et al., (1996) reported that A sawdust-derived soil conditioner promotes plant growth and improves water-holding capacity of different types of soils. Sawdust, a bulky waste generated by wood processing industries, has very few profitable and ecofriendly uses and poses a problem of proper disposal.

Mulching the soil surface with a layer of plant residue is an effective method of conserving water and soil because it reduces surface runoff, increases infiltration of water into the soil and soil moisture storage, and retard soil erosion. Ghuman & Sur (2001) found that the application of 3.0 $t.ha^{-1}$ plant residue increased the initial infiltration rate 8% and the final one as 5%. Jalota et al., (2001) reported that straw mulching (SM) significantly increased the total infiltration at the end of a 6-h infiltration test. They explained this case as the increase of water-resistant aggregates as a result of decomposition of the plant residues, Allmaras et al., (1996) explained that good soil surface conditions to of water into soil. Flinn & Wough (1983) investigated that the addition of 170 $t.ha^{-1}$ sunflower wastes to soil significantly increased infiltration capacity, but it had no significant effect on water-resistant aggregates. Gill & Jalota (1996) mixed straw with soil at 2 and 5 depths and concluded that mixing straw with soil at 2 cm depth produced better results in respect to evaporation.

SM is used as a soil conditioner to increase WHC. Brady & Weil (2002) explained the effect of organic matter content on soil WHC in two ways. The direct effects are due to the very high WHC of organic matter, and the indirect effects are its influence on soil texture and total pore space. (Ji & Unger, 2001) reported that crop residues at the soil surface serve as a vapour barrier against evaporation losses from the soil and indirect effect on WHC. Rathore et al., 1998 observed that more water retained in the soil profile with SM than without it.

Biochar is an alternative as soil conditioner and fertilizer by increasing cation exchange capacity (CEC), pH, and water retention. Biochar is defined simply as charcoal and it created using a pyrolysis process, heating biomass in a low oxygen environment. Plant residues based chars are considered a soil conditioner, rather than fertilizer, due to low leachable nutrient contents, and are most effective when used in combination with synthetic PKN fertilizer In contrast, manure-derived char can release its PKN content and function both as soil fert lizer and conditioner (Steiner et al., 2007).

Suziki et al 2007 were used different natural soil conditioner and reported that increases in the available water content were remarkably higher under termite mound material (0.21 m^3 m^{-3}) and bentonite (0.19m^3 m^{-3}) treatments when compared to the control. However, soil structural stability remained poor for the compost and termite mound applications, while the structural stability was enhanced for the bentonite treatment with increased water holding capacity. They explained that this will have positive to the rainfed cropping systems that are susceptible to periodic drought stress, thereby reducing risk of crop failure associated with low water holding capacity.

Yolcu et al 2011 investigated on application of cattle manure, zeolite and leonardite for improving crop yield under semiarid conditions. This study results showed that in most cases manure, leonardite and zeolite applications positively affected the hay yield, the macro- and micronutrients of ryegrass, and all fertilizers have potential for use in organic agriculture. Similarly Kirkik 2011 was found that the positive effects of zeolite on the physical and chemical properties of the soil, its role on the increase in the efficiency, availability in our country, K, Ca, Na and Mg content, ability of supplying N, high water holding capacity and cation exchange capacity make it possible to use it as a soil conditioner and a growing medium in agricultural lands. Tunçez 2007 was used sugar industry sludge and pumice as soil conditioner and an improvement was found on water holding capacity, organic content, N, K, P content in soil.

Despite the many materials on soil conditioners, their widespread application on arable lands has been limited, primarily because of economic considerations and its availability as natural. Therefore, an economical synthetic soil conditioner, Polyacrylamide (PAM),and easy available, local and natural materials (straw mulches (SM) and paper pellets (PP)) were chosen in this study. Their effect on soil infiltration, AS and WHC, hence, evaluating probability of these wastes were investigated.

Materials and Methods

Field experiments were conducted in a soil with high clay content and low IR (soil-1) to investigate the effects of applications on infiltration and in a relatively coarser-textured soil (soil-2) to investigate AS and WHC in Kahramanmaras plain, in the Mediterranean region of Turkey with 37^{o} 35' N, 35^{o} 56' W and altitude of 520 m (Fig.1). Some physical and chemical properties of soils studied are tabulated in Table 1.

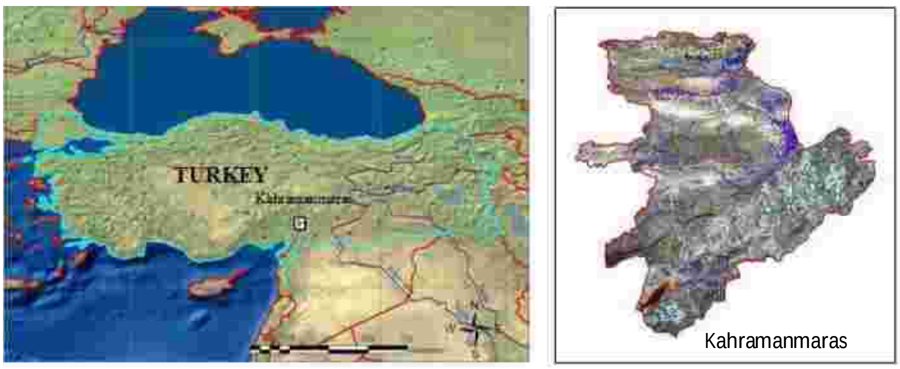

Figure 1. The study area on the map of Turkey.

Table 1. Some physical and chemical properties of soils in the study area

Soil type	Texture (%)			FC*	PWP	BD	EC	pH	OMC
	Clay	Silt	Sand	Pw (%)	Pw (%)	($g.cm^{-3}$)	($ds.m^{-1}$)		(%)
Soil-1	38.0	14.3	47.7	41.9	31.3	1.23	1.445	7.67	1.86
Soil-2	11.2	10.9	77.9	17.1	13.0	1.39	0.513	7.97	1.16

*FC: Field capacity, PWP: Wilting point, BD: Bulk density EC: Electrical conductivity, OMC: Organic matter content

Treatments were the application of irrigation water containing 10 $mg.L^{-1}$ PAM (charge density of % 20, molecular weight of 14-18 million $mg.mol^{-1}$), 1.25 and 2.5 $kg.m^{-2}$ SM (SM1 and SM2), and 1.25 and 2.5 $kg.m^{-2}$ waste PP remained during wheat straw-based paper production (PP1 and PP2). After soil tillage, SM and PP were uniformly distributed on the soil surface. After the second tillage soil conditioners could be mixed with soil up to the 30 cm.

Double-ring infiltrometer was used in the determination of initial and final IRs by following the procedures of Walker & Skogerboe (1987). AS analysis was made by following the procedures of Tuzuner (1990). One year after the preparation of experimental plots, soil samples taken from 0-30 cm were air-dried and then sieved in 2 and 1 mm sieves in this order. Ten g of soil on the surface of 1 mm sieve was taken and then oven-dried (W1). Besides, a sample was sieved in water by a 0.25 mm sieve for 5 minutes. The dry weight (W2) and sand content (W3) of soil on the surface of sieve (0.25 mm) were determined. AS is calculated as:

$$AS\,(\%) = \frac{(W2 - W3)}{(W1 - W3)} \times 100$$

Organic matter content (OMC) was determined by the modified Walkley-Black method (Black, 1965). Soil WHC characteristics, field capacity (FC), and permanent wilting point (PWP) were determined using soil samples on a tension table (33 kPa) and pressure plates (1500 kPa) (Klute, 1986). Available water content (AWC) was calculated as the difference between FC and PWP and presented as volumetric basis. Soil bulk density (BD) was measured with undisturbed cores (100 cm^3). All treatment results were statistically compared by using multiple Duncan t-test.

Results and discussion

Infiltration

The initial IR was taken for the first 5 minutes at infiltration test, and to obtain final IR (basic infiltration) was continued until steady state flow conditions. Statistical analysis was made by considering the initial and final infiltration values each application, and the results are presented in Table 2.

Table 2. Initial and final infiltration rates for different treatments

Treatment	Initial IR $mm.h^{-1}$	Final IR $mm.h^{-1}$
Control	93.3 d*	28.6 b
PAM	118.0 b	28.7 b
SM1	96.0 d	30.7 ab
SM2	104.0 c	30.0 ab
PP1	116.0 b	31.3 ab
PP2	137.3 a	32.0 a

*Means following same letter in column do not differ significantly at P =0.05 probability level

The effects of treatments on infiltration were especia in the initial IRs. The treatment PP2 increased infiltration at the highest rate, whereas in SM2 application with higher soil conditioners content similar effect was not observed. However, SM2 treatment was more effective than the control treatment. The dosage used in SM2 treatment did not affect infiltration, but this effect was observed in parallel to the increase in dosage. In general, the effects of applications on final IR were limited. This may be due to the fact that subsoil with no soil conditioner limits final IR. However, PP2 treatment had positive effect on final IR may be because of more water flow through soil having soil conditioners.

In a study conducted by Wuest et al., (2005), 22.4 $Mg.ha^{-1}$ fresh manure and 2.24 $Mg.ha^{-1}$ pea vines application increased three or four times the po d IR. They concluded that this was the result of the fast effects of these applications on macropores. Similar case may be considered to be valid for PP used in this study. On the other hand, Pikul & Allmaras (1986) reported that preferential flow played a significant role on the wide range of the initial IRs in tilled soils. Therefore, it is more appropriate to evaluate the effects of the applications on infiltration by considering the final IR. However, during irrigation applications, the initial IR had also significant effect on infiltration.

In several studies on PAM applications, it was reported that PAM applications significantly increased IRs (Lentz & Sojka, 1994; Francisco & Richard, 2000; Sojka & Entry, 2000). However, in this study, even though PAM application had positive effect on IR, this effect was statistically not significant on the final IR. Ajwa & Trout (2006) reported that PAM application decreased IR as a result of rapid aggregat in especially sandy-loam soils. The other reason of this effect is that PAM increases the viscosity of irrigation water but decreases the movement of PAM-applied water (Francisco & Ricard, 2000). However, the opposite is true for heavy-textured soils where high level of runoff is observed. In this case, as the viscosity of water increases, runoff decreases and infiltration increases. The other important point here is that the effect of PAM application on IR depends upon the selected irrigation method.

Aggregate stability

Table 3. Aggregate stability and organic matter content

Treatment	AS (%)	OMC (%)
Control	2.81 d*	1.1 d
PAM	9.95 a	1.0 d
SM1	3.92 c	2.1 c
SM2	5.70 bc	2.7 b
PP1	5.44 bc	3.2 ab
PP2	7.01 bc	3.6 a

*Means following same letter in column do not differ significantly at P =0.05 probability level

Highest increase in AS was observed in PAM application (Table 3). Busscher et al., (2007) reported that addition of PAM to the soil increased penetration resistances and decreased BD. The increase in the strength was an indication of better aggregation. Lentz et al., (2001) reported that PAM had effects in two different ways: 1) PAM is adsorbed onto soil surface, increasing soil cohesion and AS, and 2) PAM flocculates fine soil particles suspended in the furrow stream, producing larger aggregates that tend to settle out of the flow. In the other applications, in general, AS clearly increases paralle to OMC. Similar results were reported by Chaney & Swift (1984) and Bartoli et al., (1988).

PP application was more effective on OMC and AS compared to SM. This may be because of rapid decomposition of PP in soil. Unger (2001) used P as the surface mulching and found that PP applications did not affect water storage apparently because PP absorbed precipitation, which resulted in similar evaporation from bare and mulched soils. PP applications resulted in greater aggregate mean weight diameters and lower percentages of small aggregates. These improved conditions could improve the long-term productivity of soils. However, shallow paper incorporation may be a better practice than surface applications because it should hasten its decomposition and, thereby, more rapidly improve soil conditions.

Water holding capacity

The results of FC, PWP, and AWC were presented in Figure 3. AWC values were determined for 1 m soil depth and treatments were compared with Duncan t-test (Table 4).

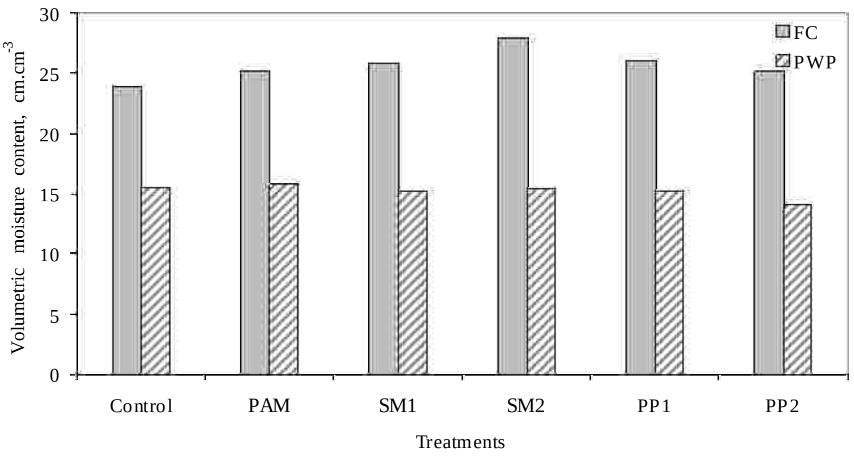

Fig. 3. Field capacity and permanent wilting point for each treatment

Table 4. Soil available water content and bulk density results

Treatment	AWC ($mm.m^{-1}$)	BD $gr.cm^{-3}$
Control	83.3 c	1.393 a
PAM	93.4 bc	1.497 a
SM1	106.1 ab	1.424 a
SM2	125.5 a	1.496 a
PP1	107.9 ab	1.419 a
PP2	110.4 ab	1.363 a

*Means following same letter in column do not differ significantly at P =0.05 probability level

Significant effects of treatments on soil volumetric moisture content were observed at low suction (FC). Applications increased moisture content at FC in different levels. This increase was at the most in SM2, PP2, PP1 and SM2 treatments. can be concluded that SM2 treatment increased FC, possibly due to the fact that SM used in SM2 treatment increased soil porosity more than soil moisture content (Brady & Weil, 2002).

PAM application had no significant effect on FC and AWC. It was observed a relative increase in AWC as a result of the increment in AS paralel to PAM application and improvement in porosity. Previous studies indicated that PAM dosage of $10mg.L^{-1}$ was suitable for infiltration improvement and erosion control as shown in this study. Since the increase of this dosage will lead to an increase in moisture content of PAM, positive results for AWC can be expected.

In general, there was no significant change in PWP values. The treatments had similar results under high pressures (1500kPa). Mulumba & Lal (2008) found that wheat SM application rates of 0.2-16 mg.ha^{-1} had no effect on PWP.

AWC was also influenced by mulching, being significantly lower in control treatment (CT) compared to mulched treatments. The application of mulching even at low rates can have a significant impact on AWC. Mahboubi et al., (1993) reported that high AWC was usually associated with high application of crop residues and Similar observations were made by Duiker & Lal (1999).

The applications had no significant effect on BD. Normally, a decrease in BD is expected with an increase in mulching material, but contradictory results were obtained in different studies. While some researchers observed reduced BD under mulches (Unger & Jones, 1998), some others found increased BD (Bottenberg et al., 1999), and yet he others observed no mulch effect on BD (Acosta et al., 1999; Duiker & Lal, 1999). This may be due to the fact that pore structure can be influenced by the amount and properties of mulching materials and soil type.

Conclusion

That wheat SM and PP effects are observed even within one-year study period shows that their future effects may be even more consistent. As llel to OMC, the increase in micro- and macropores causes an increase in water-resistant AS and decrease in dispersion (Masri & Ryan, 2006). This can be seen an advantage of PAM where it is especially effective in only irrigation application which is used with it (Lentz & 1994) and it has limited effect on infiltration in ponding irrigation conditions. Due to the persistent effects of wheat SM and PP, their low costs and evaluation of wastes, the use of wheat SM and PP can be suggested in order to improve IR or increase AS in lands under erosion. PAM application at the defined dosages had no significant effect on WHC. However, the other mulching applications depending upon the increase in mulching rate improved thereby AWC. In addition to the application of irrigation planning criteria, mulching will lead to increased soil WHC, thereby efficient use of available water. Besides, mulching w ll reduce not only labor and cost but also soil and water losses occurred in each irrigation application by decreasing the number of irrigation at certain time interval.

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