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Effect of subsurface water retention using polyethylene membranes with surface mulch and irrigation on moisture, temperature and salinity of sandy soil of an arid region in Iran

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Abstract. Soil water deficits and associated plant water stresses comprise the greatest abiotic hindrance to sustainable plant growth. Essential supplemental irrigation without water conservation practices is expensive and often contaminates groundwater, it usually decomposes rapidly, and is time consuming. Subsurface water retention technology (SWRT) is a new method which reduces deep drainage and leaching and many of the ecological and environmental dilemmas occurring among today's crop production enterprises established on highly permeable sandy soils. Therefore, this study was established to investigate the resilient contributions of the SWRT on soil moisture, temperature and electrical conductivity of a sandy soil. Additionally, surface applied straw mulch treatments were added to these membranes to identify separate and combined contributions to maize yields in an arid region of Kerman, Iran. This field study was performed in a completely randomized block design with three treatments: i) depths of polyethylene membrane, ii) surface straw mulch and iii) irrigation water quality. All treatments were under maize cultivation in June 2013. Results demonstrated that installing water-saving SWRT membranes below plant root zones reduced the frequency of irrigation compared to controls without membranes. Soil water reductions were slower in SWRT membrane treatments. Water loss was reduced even more when surface mulch was added to soils equipped with SWRT membranes. Soil temperature reductions at various depths in SWRT membrane treatments plus straw surface mulch were greater than when SWRT membranes were installed without straw mulching of the soil surface.

Key Words: dry climate, straw surface mulch, sandy soil, subsurface water retention technology, water-saving membranes.

Introduction. The development of non-traditional new technologies to conserve water is becoming important for attaining a sustainable economic growth, especially in agricultural countries (Shahid et al 2012). Improving the efficiency of irrigation water by different methods is one of the economically viable alternatives in overcoming the water scarcity. Sandy soils will be very productive when water is wisely managed both above and within the soil. Consequently, subsurface water retention technology (SWRT) is a promising solution to overcome the fight against hunger especially in the developing countries (Ismail & Ozawa 2007). This is not only crucial for the sustainable agricultural yield but also to meet the challenges of current environmental issues and justice, financial problems and physical barriers in the developing countries (Ahmed et al 2012). The main problems of sandy soil are moisture holding capacity and nutrients deficiency and clay soils holding high moisture content, but water use efficiency at the interface of Field Capacity and Permanent Wilting Point is maintained with little suction in sandy soils. Therefore, the sandy soils can be very productive if the water is to be managed wisely (Shorafa 1987).

Small-scale irrigation technologies and precision agricultural management practices from water harvesting and collection to storage within the root zones of plants will help optimize water usage for each farmer. New SWRT, coupled with precision water and nutrient management, has the potential to transform agriculture, reduce poverty, and improve nutrition among the rural poor globally. Overcoming short-term and long-term water deficits for agricultural plants is a primary step forward to maximize newly developed hybrids, associated with best management and protection of harvested produce. Although estimates of food insecurity vary, Barrett (2010) concludes that feeding these many people requires more than incremental changes. Fedoroff et al (2010) outline how scientists and engineers can make a big difference at every step from field to fork and we propose it will take a trilogy of new technologies to produce more crop grain and biomass per drop of water as defined by Ash et al (2010).

Subsurface soil water retention membranes, installed within plant root zones, comprise a self-regulating type of technology that improves the production of food and cellulosic biomass and increases water use efficiencies for the dramatic expansion of food, fiber, and cellulosic biomass production needed by the rapidly expanding global populations. It is anticipated that these water savings will also diminish the growing competition for water among regional and economic sectors (Smucker et al 2014).

Studied results of Demirel & Kavdir (2013) showed that placement of SWRB at 40 cm depth (SWRB40) together with 34% water deficit saved 52% irrigation water compared with the control (no SWRB) treatment. In separate studies was showed that surface soil mulching has usefull effect on soil temperature and moisture and decreasing of the damaging effects of salinity water and soil resources(Chen et al 2007, Jordán et al 2010, Aragues et al 2014, Deshmukh et al 2013, Al-Dhuhli et al 2010, Bezborodov et al 2010). However investigation on the effect of both SWRT membranes and surface straw mulch on the soil moisture, temperature and salinity changes in different depths of soil, especially in coarse textured soils of arid regions, has not been studied. Hence, this project was designed to investigate the effects of subsurface water saving membranes, installed at multiple depths in a sandy soil with and without surface straw mulches, influenced soil moisture and temperature, electrical conductivity within sand profiles increased SC.704 maize yield in the Kerman arid region of Iran.

Material and Method. The experiment was conducted at research station of agriculture and natural resources research center located at Kerman, Iran, from the end of February 2013 to the end of November 2014. The climate is dry with a mean annual precipitation of 145 mm, average temperature of 15.9^{o}C (Applied Research Center, Department of Meteorology 2013). Soil texture is sand (Table 1).

Before applying treatments, soil samples were taken at intervals of 30 cm from the soil surface to depths of 90 cm. Soil physical and chemical properties were measured from these soil samples. Saturation percentage (SP) by measuring of water content of saturated paste, soil texture (hydrometer method (Page et al 1982)), electrical conductivity of soil saturation extract (ECe) (Jenway model 4520, Designed and Manufactured in the UK by Bibby Scientific Ltd, Gransmore Green, Felsted, Dunmow, Essex, England-CM6 3LB, UK), pH (in water), calcium and magnesium and sodium of soil saturation extract (in water). Also, field capacity (FC) and permanent wilting point (PWP) were measured using pressure plate (Table 1).

Table 1

Physical-chemical analyses of studied field sand

Texture	*Clay (%)*	*Silt (%)*	*Sand (%)*	*P.W.P (%)*	*F.C. (%)*	pH	*Ece (dS m^{-1})*	*SP (%)*	*Depth (cm)*
Sandy	2	4	94	6.39	10.46	8.1	0.6	40.89	0-30
Sandy	2	4	94	3.2	9.67	8.2	0.6	36.60	30-60
Sandy	2	4	94	3.51	7.9	8.1	0.5	40.73	60-90

Soil moisture content in different treatments was measured at intervals of one day by using TDR. Moisture measuring depths in different treatments were as follows: control: 20 and 40 cm; P60: 20 and 40 cm; P40: 20 cm; P40-60: 20 and 40 cm.

According to a survey conducted by Ebrahimizade & Hassanli (2008), they reported that in stream irrigation of corn about 80% of dry weight of root is in 0 to 40 cm soil depth.

Therefore we installed polyethylene (PE) membranes below these depths in three depth treatments (membrane installation depths at 40 cm (P40), 60 cm (P60) and alternate 40 and 60 cm (P40-60). To investigate the effect of straw mulch with SWRT membranes was used two mulch treatments (surface mulching with straw wheat residue (4 t ha^{-1}) (M) and no straw (NM)). Given that one of the problems in agriculture is the lack of high quality water and in order to assess SWRT method on distribution of salinity in soil due to irrigation with saline water, consequently we added two irrigation water qualities to this study. The two irrigation water salinities for this study were ECe 1.5 (I1.5) and 3.5 dSm^{-1} (I3.5). Therefore, the experiment consisted of 3 variable factors: membrane installation depth, mulching, and water quality that were replicated 3 replications in completely randomized block design. Total number of plots was: 3 x 2 x 2 x 3 = 36. Each plot area was 8 m^2 (2 x 4 m). In Figure 1 is shown a diagram of the polyethylene membrane distribution, below the plant root zone. Based on farmers activity, a treatment without membrane installation, without straw mulch, water quality 1.5 dS m^{-1} was selected as control.

In June 2013, corn was cultured with row spacing of 60 cm and 20 cm between plants in each row.

During the growing season, whenever the soil moisture reached at 70% field capacity irrigation was done. To investigate the effect of straw mulch on soil temperature during the growing season, soil temperature at a depth of 5, 10 and 20 cm were measured by Hg thermometer installed in the target depths. After harvesting, the electrical conductivity of soil saturation extracts were measured at 5 cm intervals to a depth of 60 cm in all experimental plots.

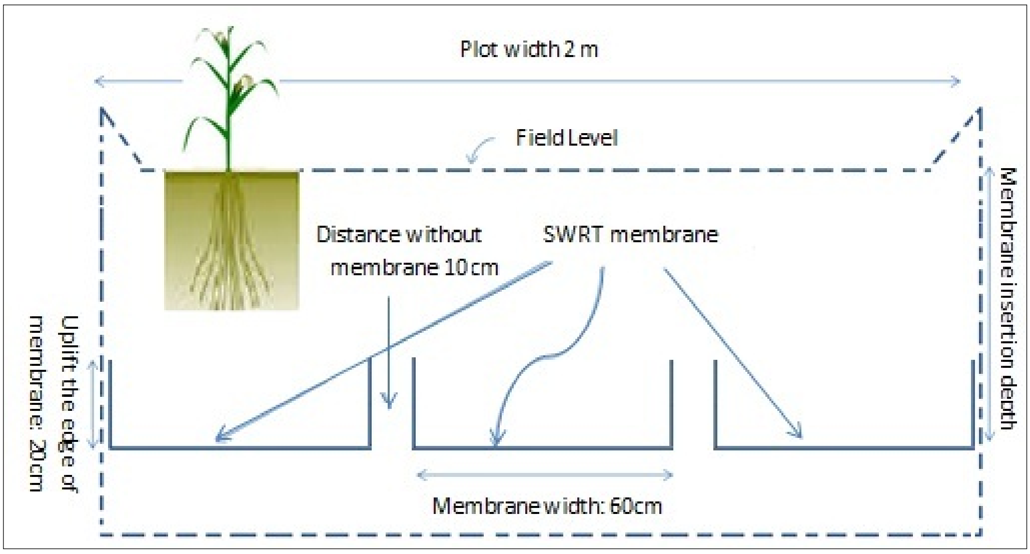

Figure 1. Form of polyethylene membranes distribution at desired depth.

Normality test was done on obtained data to study the effects of different treatments on the soil moisture, temperature and EC at various depths, then the data was analysed by using SAS software and related calculations and drawing graphs were done by Excel.

Results and Discussion

Effect of SWRT membranes on soil moisture. Water-saving membrane can store incoming water from open ditch irrigation under soil surface, and used to continuously supply optimal plant water .This process affects on some common processes such as soil moisture within the membranes and the water lifted into the plant root zone, by capillary rise (Smucker & Basso 2014) of these water-saving membranes. So one of SWRT membranes effects is on soil moisture changes that have been evaluated at depth of 20 cm over time.

Figure 2 shows that soil moisture changes in at all soil depths of installed SWRT membranes are more gradual than control (without water-saving membranes). As a control, there is no barrier to keep water in the soil, irrigation water can permeated more deeply into the sand profile well below the plant root zone. In less than a day after irrigation, soil moisture content will reach less than 70% of field capacity and needs to be re-irrigated. The trend of moisture change in SWRT treatments were almost the same, and only in the last days the rate of water loss from P40 was more than P60 and P40-60. Evaporation of water from the soil is more in P40 because the membrane is closer to the surface compared with P60 and P40-60. Soil water change in I1.5 (Figure 2-a) is more than I3.5 (Figure 2-b).

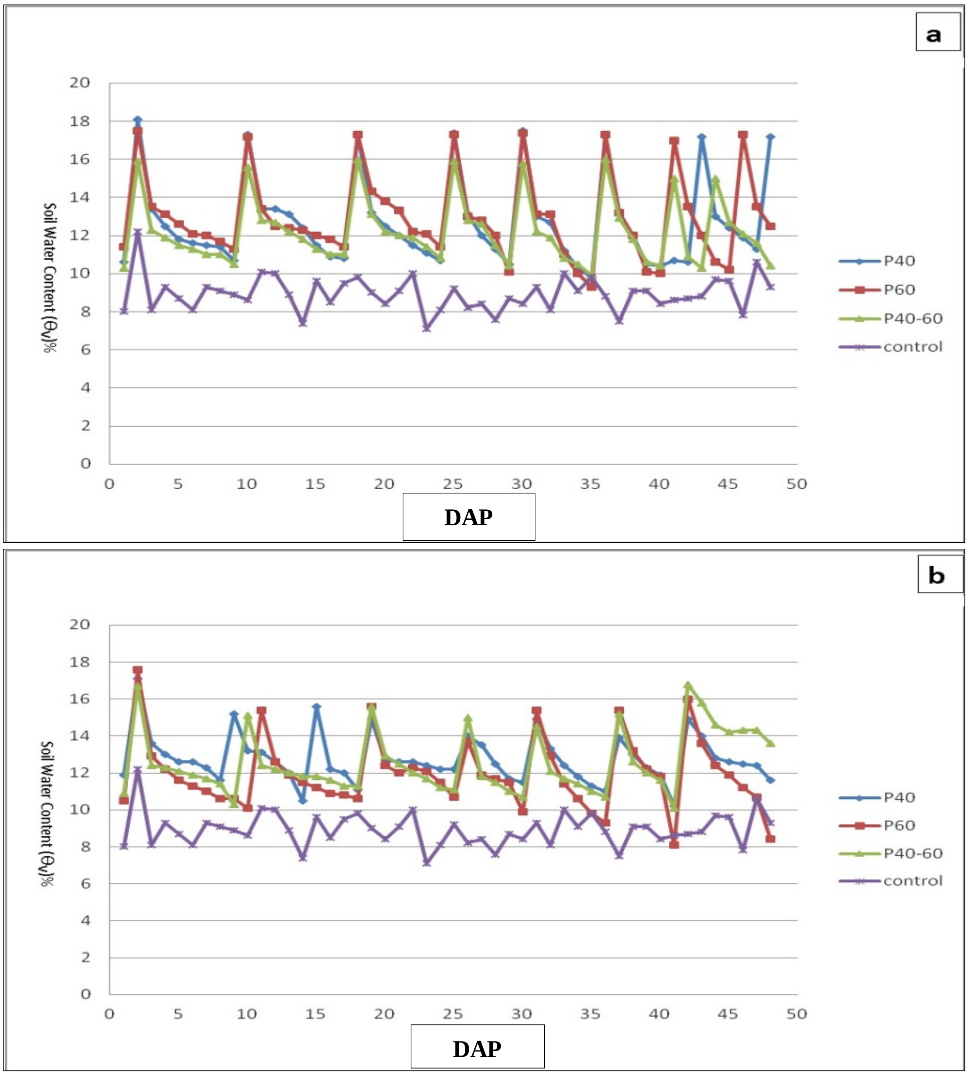

Figure 2. The effect of SWRT membrane depth on moisture changes with use of mulch (a: I1.5 and b: I3.5) (DAP: days after planting).

Also, soil moisture changes in the non-mulching conditions are less than the controlled SWRT membrane (Figure 3). The speed of moisture reduce was increased at the end of period in SWRT treatments which coincides with the corn plants that are larger. Soil moisture changes in Figure 3-a is more than 3-b due to low water salinity. In this figure, it can be seen that in most cases soil moisture before irrigation (control) is less than the SWRT treatments. A soil moisture change in P60 is more gradual than in P40-60. In this regard, part of the water at a depth of 40 cm in P40-60, where the membrane is installed closer to the surface, the evaporation rate is higher. The frequency of irrigation needed for corn in SWRT treatments is reduced compared to the control ($p = 0.01$) (Table 2). Number of water applied (irrigation) in terms of control was 45 times and it fell to 26, 24 and 26 times for P40, P60 and P40-60, respectively. To prevent water loss through evaporation from the surface, straw mulch was added on the soil surface, thus irrigation in these conditions was reduced to 20, 20 and 21 times, respectively. Smucker & Basso (2014) showed that soil water permeability losses by drainage in sandy soils without water-saving membranes were 8200 liters per square meter per day (L m^{-2} d^{-1}). According to Table 2 it can be seen that treatments of water-saving membranes, use of mulch and irrigation water quality have a statistically significant effect on soil moisture. Also, results of a 3-years experiment by Jordán et al (2010) showed that mulching application increased the available water capacity.

Table 2

Anova for irrigation times in SWRT membranes and surface mulch treatments

Source	*DF*	*Mean square*	*F value*	*Pr > F*
replication	2	3.1794872	0.75	0.4850
mulch	1	210.2500000	49.32**	0.00001
depth	3	283.0555556	66.40**	0.00001
irrigation	1	26.6944444	6.26*	0.0195
depth*irrigation	2	2.0277778	0.48	0.6272
mulch*depth	2	7.7500000	1.82	0.1840
mulch*irrigation	1	3.3611111	0.79	0.3834
mulch*depth*irrigation	2	1.3611111	0.32	0.7297
Error	24	4.262821		
CV = 8.54				

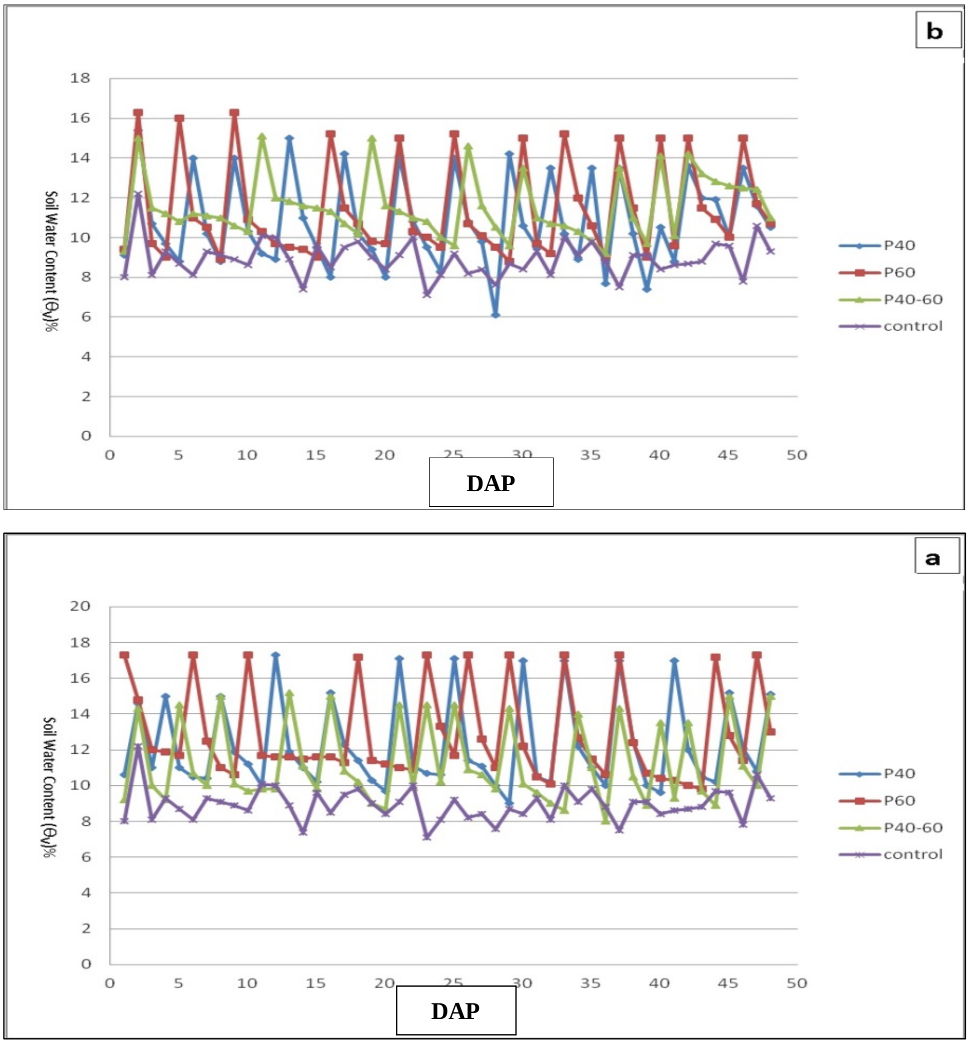

Figure 3. The effect of SWRT membrane depth on moisture changes without use of mulch (a: I1.5 and b: I3.5) (DAP: days after planting).

Soil temperature. Changes in soil temperature during the growing season were evaluated in the depths of 5, 10 and 20 cm of soil. The results showed that the soil temperature at studied soil depths 5 and 10 cm in terms of control were higher than P40, P60 and P40-60, and the difference in temperature at a depth of 5 cm was more visible (Figures 4 and 5).

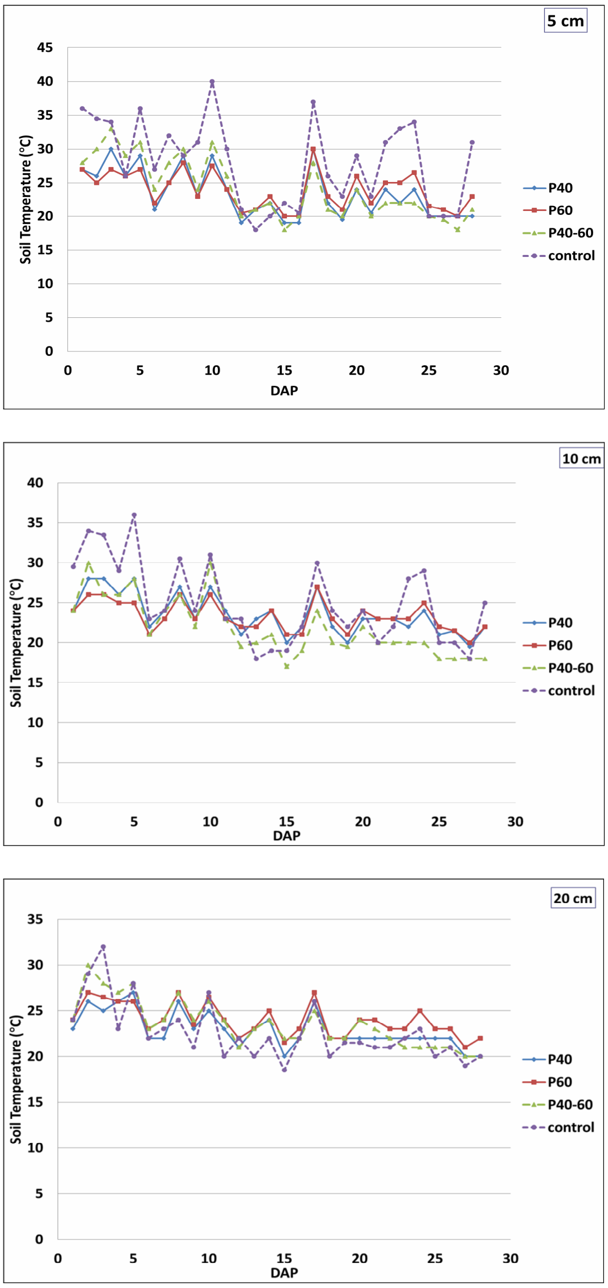

Figure 4. The effect of SWRT membrane depth plus surface straw mulch on soil temperature at 5 and 10 cm and 20 cm.

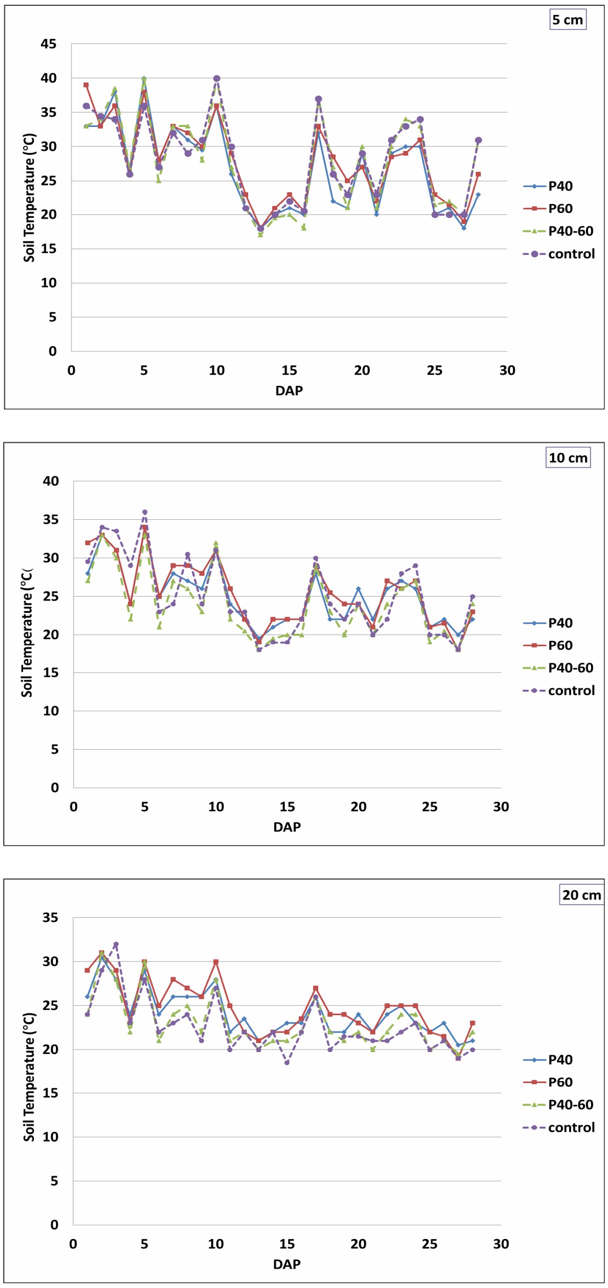

Figure 5. The effect of SWRT membrane depth without use of mulch on soil temperature at 5 and 10 cm and 20 cm.

It was observed that the difference between the recorded temperatures was reduced by increasing the depth for each of the treatments. The soil temperature range of 5, 10 and 20 cm of soil for SWRT treatments in the use of mulch was in the 18-33, 17-30 and 20-30°C, and in the absence of mulch application ranged from 17-40, 18-34 and 19-31°C, respectively. The study of Chen et al (2007) has shown that the existence of straw on the soil surface reduced the maximum, but increased the minimum diurnal soil temperature. The temperature range of 5, 10 and 20 cm in control was between 18-40, 18-36 and 18.5 to 32°C, so this data suggests that although the control was irrigated every day, the water could not adjust the soil temperature due to lack of water maintenance in the soil. On the other hand, despite the lack of difference between soil temperature data of control and no-mulch in SWRT treatments, the rate of temperature increase was higher in the control plots. So, there is plant heat stress in this treatment, which has a negative effect on soil moisture, plant growth and crop yield.

Electrical conductivity of soil saturation extract (ECe). According to the data obtained in the installation membrane treats, there was more salt accumulation in the surface layer without the mulch treats than treats with mulch (Figure 6). Also, studies conducted by Aragues et al (2014), Deshmukh et al (2013), Al-Dhuhli et al (2010) and Bezborodov et al (2010) had the same results. ECe in various treats of polyethylene membranes installation depths had no significant difference in comparison to the SWRT membranes without the treat (control) (Figure 6). The polyethylene membranes presence in soil depth and water retention for plant use under soil surface had no significant effect on increasing salinity of soil surface layer. So it can be concluded that the application of polyethylene membranes have no restriction in soil with high salinity.

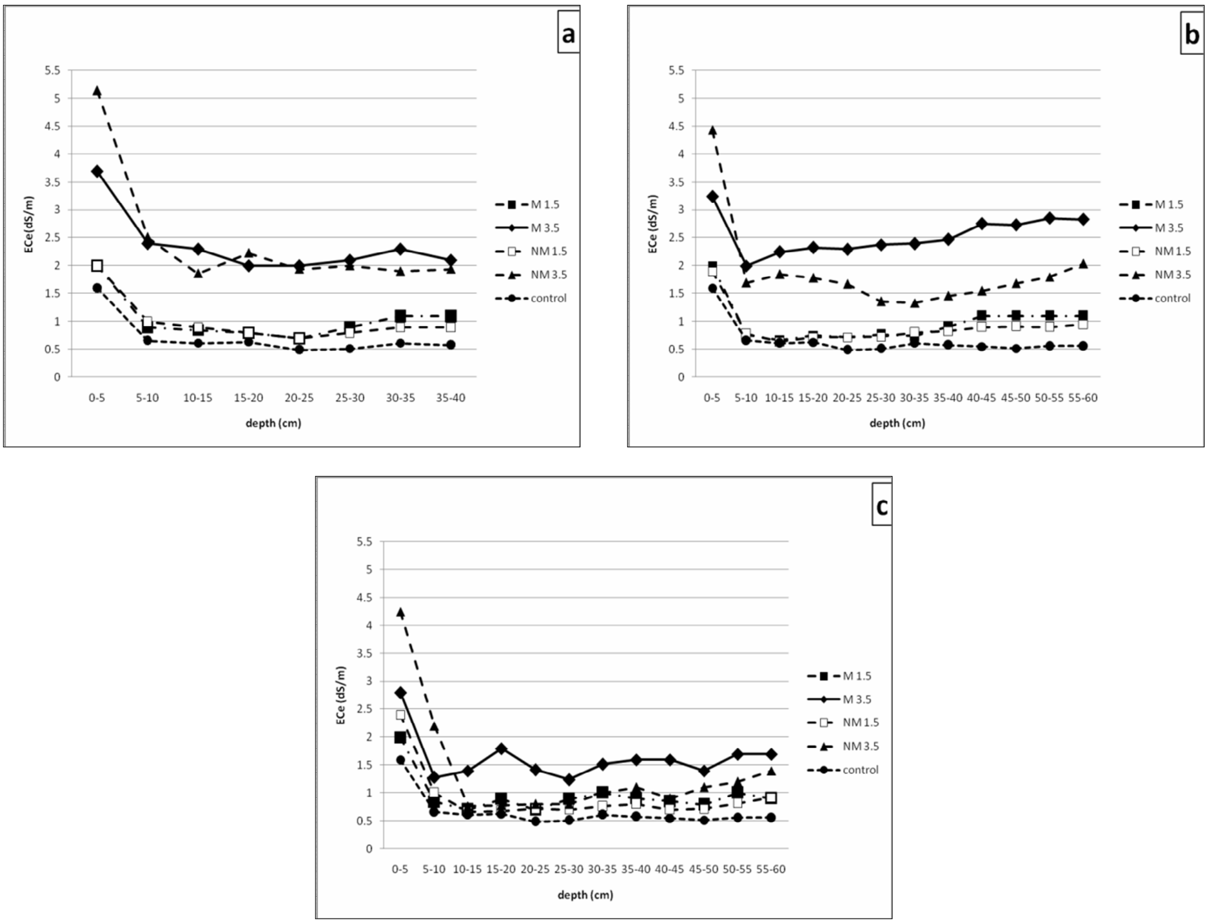

Figure 6. Effect of mulch and irrigation water salinity on ECe of different soil layers (a: P40, b: P60 and c: P40-60).

Conclusions. In general, soil moisture and soil temperature conditions could be improved by using water-retaining membrane. So that the number of irrigation times decreased. The trend of soil temperature at depths of 5, 10 and 20 cm was the most in control. In other words, we can assume that the SWRT membranes are not a restriction in agriculture, but they have positive effects on water retention for plant and moderating soil temperature. The using of surface mulch also have a significant effect on improving this soil characteristics.

Finally, it is suggested that using SWRT membrane with surface mulch is a scientific method to improve condition of sandy soils and arid areas.

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