Effects of plastic sheet on water saving and yield under furrow irrigation method in semi-arid region

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Abstract: The increasing demand of water in the country highlights the need to introduce low-input and water saving technologies for agricultural sustainability and crop production, mainly in semi-arid region. A study was conducted to minimize deep percolation losses from the furrow bottom under two different irrigation treatments viz. (1) furrow bottom with plastic sheet (T_1) and (2) furrow bottom without plastic Sheet (T_0). The physical and chemical analyses of soil profile were taken at a depth of 0-80 cm before and after crop harvesting. The dry density of soil slightly increased (0.01 g/cm^3) under both treatments, while soil pH decreased under T_1. The average yield was 8332 kg/hm^2 and 7575 kg/hm^2, with 21.56 m^3 and 31.09 m^3 total volume of irrigation water applied under $T_1$and T_0, respectively. The saving percentages of water under treatments were 52.22% and 31.00% under T_1 and T_0 respectively as compared to the saving of water under traditional irrigation practice. Overall, better performance, in terms of crop production and water saving, was obtained with use of plastic sheet integrated with bottom of furrows. Hence, it is suggested that the furrow irrigation method with plastic sheet may be used to preventing moisture and minimize deep percolation losses from furrow bottom.

Keywords: furrow irrigation, semi-arid region, water saving, yield, plastic sheet, deep percolation, okra crop, soil pH
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1 Introduction

Pakistan is an agriculture country, which falls within semi-arid to arid climatic zones. Its irrigated areas are under the pressure of water shortage while the rain-fed areas are severely affected by drought[1,2]. However, under these circumstances, the proper use of water resources with ideal outputs should be important and the basic objective for sustainable agricultural production[3,4]. The increasing demand of water for irrigation supply in the country emphasizes the important need to introduce low-input and water saving technologies for agricultural sustainability and crop production, mainly in arid and semi-arid areas[5,45].

Agriculture sector remains as the domination of water requirements for the irrigation purpose[6]. Moreover, semi-arid and arid regions of the country with the increasing population, urbanization and unsustainable consumption of water have further imposed the greater demands of water[7,8]. Thus, it becomes indispensable to properly manage water resources at all levels in order to fulfill food and fiber requirements of growing population. The growing demand for water aimed to improve the overall efficiency of the system with particular approach focus on increasing water use efficiency (WUE) at field level[9,10].

In Pakistan Basin, border and furrow are the traditional surface irrigation methods, which are used to irrigate crops[11,12]. Closely related furrow irrigation is the surface irrigation which utilizes the water for irrigation more efficiently as compared to other surface irrigation methods[13]. Furrow irrigation is the water shortage technique which considerably improves WUE, reduces irrigation, increases crop production with the shortage of water supply, and has low permeability and less seasonal water logging condition[14]. The method is suitable for row crops which are sensitive to standing water and the crop is planted on the ridges between furrows, which may contain a single row of plants[13]. Furrow irrigation provides better on-farm water management capabilities, reduces the flow rates per unit width, and is applicable to more severe and variable topographical conditions[15]. In addition, the operational flexibility is also important for achieving higher efficiency for each irrigation method throughout a season[9,16].

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Mugnozza et al.[17] reported that the use of plastic sheet mulch in agriculture sector is a global phenomenon with an increasing trend. Use of plastic sheet mulch in agriculture is beneficial to soil physical, biological and chemical conditions for better crop performance[18,19]. The using of the plastic sheet at furrow bottom can reduce the loss of fertilizer and nutrient through leaching, and provide a barrier to soil pathogens[3,20]. Plastic sheet decreases the germination of weeds and repel certain insects. Additionally, plastic sheet provides a stable environment especially at night to promote seed germination[21]. Rodrigues et al. and Jin et al.[22,23] studied that the using of plastic sheet in agriculture was mainly employed for the reduction of irrigation frequency and water saving.

Bai et al.[24] reported that micro-collecting practice of rainwater increased the WUE as compared to the plastic sheet used for flat planting practice and the conventional planting practice. Wang et al. and Fang et al.[25,26] showed that the WUE and potato production improved significantly under plastic sheet treatment and ridge planting. Wang et al.[27] reported that the using of plastic sheet was capable of promoting deep soil water, improving crop growth, accelerating the soil-plant-atmosphere transport and significantly improving crop WUE. Hatami et al.[2] examined that the using of plastic mulch treatments in the field had significantly increased the yield and yield ingredients, affecting the traits of tomato and weed species.

Jiang et al.[28] conducted a study and indicated that the percentage of WUE and water saving of mung bean were higher by 22.73%-40.38% as compared with those of flat farming practice. Rong et al.[29] conducted an experiment to determine the influence of ridge-and-furrow rainfall harvesting systems using plastic film in different patterns on water-use efficiency and maize yield. The results indicated that higher maize yield and water-use efficiency was found with plastic film up to 35%, while the average water-use efficiency increased by 30%, whereas okra (*Abelmoschus-esculentus* L) was proposed as an indicator crop cultivated in field plot, which was an important vegetable sown in sub-tropical and tropical regions of world. Okra is rich in vitamins, calcium, potassium and other minerals matter and is an important vegetable crop of the summer season cultivated using furrow irrigation method. In view of the importance of plastic film sheet in water conservation practice, this study was performed with the use of plastic sheet to cover furrow bottom under furrow irrigation method for effective use of water as compared to without plastic sheet under furrow irrigation method. The aim of this study was to evaluate the water saving with furrow irrigation method by minimizing infiltration from the furrow bottom and impact on the crop growth and yield using plastic sheet at furrow bottom.

2 Materials and methods

2.1 Description of the experimental site

The present study was conducted at the experimental site of Faculty of Agricultural Engineering, Sindh Agriculture University Tandojam, Sindh Pakistan (Figure 1) during May-July, 2014-2015. The field is located at Latitude of 25.2528^o N and Longitude of 68.3224^o E at an elevation of 26 MSL, while the irrigation water supply was ground water. The meteorological data, i.e., mean monthly temperature, rainfall and pan evaporation rate were collected from the metrological observatory of Drainage Reclamation Institute of Pakistan (DRIP) Tandojam. The average monthly temperature were recorded 34.7 ℃, 33.8 ℃, and 33.6 ℃ and 10.40 mm, 10.27 mm, and 9.95 mm were noted for the average monthly evaporation rates for May, June, and July respectively. The rainfall was 0.17 mm during the entire crop growth period in the experimental area.

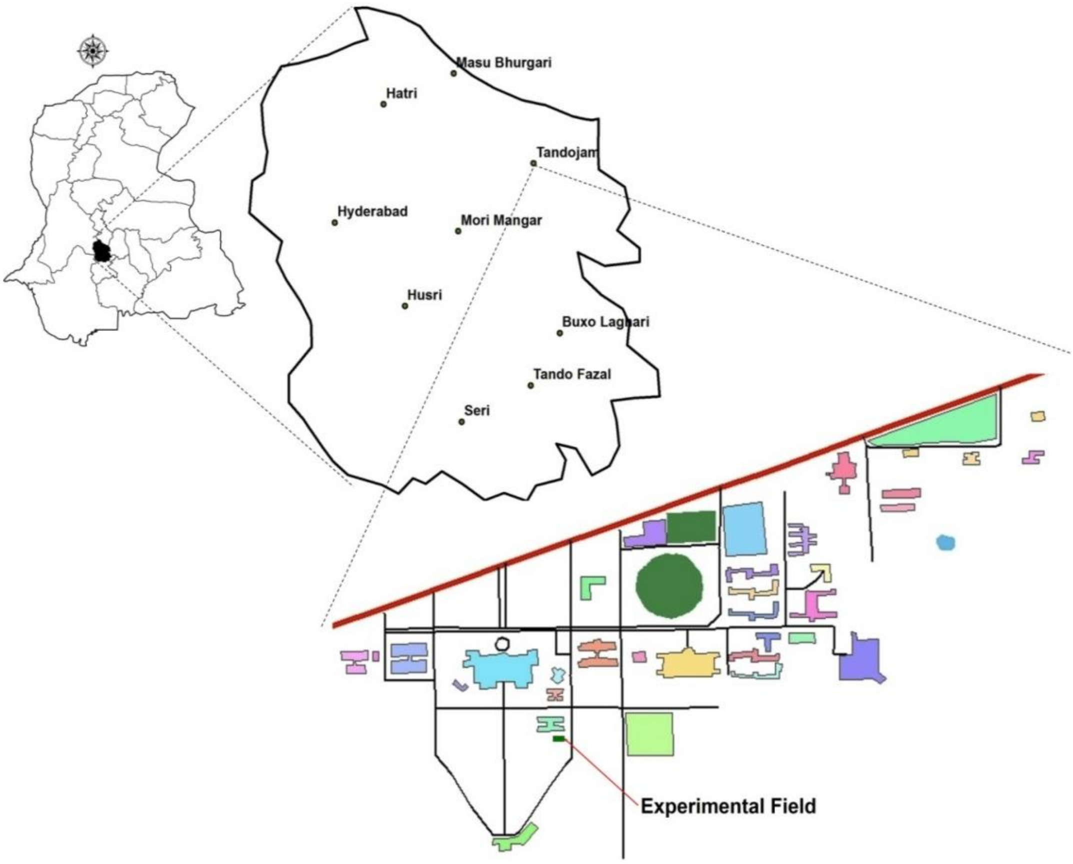

Figure 1 Geographical location of study site

2.2 Experimental design and layout

The plot selected for the experiment was of size 12 m×11 m (132 m^2) and each treatment (T_1 = Furrow bottom with a plastic sheet and T_0 = Furrow bottom without the plastic sheet) was arranged under Randomized Complete Block Design (RCBD) with six times replication.

2.3 Land preparation

The experimental site was arranged with the application of irrigation water for 80 mm as a soaking dose, whereas the seedbed was performed with ploughing of disc harrow and moldboard plough. After completion of each treatment, the length for each furrow was 11 m while the width for each ridge was 0.50 m, and the plastic sheet film was placed to cover the furrow bottom in treatment T_1.

2.4 Crop parameters

June to July and February to March are the two growing seasons of okra. The total water requirement for okra in whole growing season is 500 mm[30]. For enhancing the germination of okra yield, the seeds were soaked for 6-8 h in water before sowing. After the soaking period, the seeds were sown manually on both sides of ridges with a plant x plant spacing of 25 cm. The sowing date of the okra was 8th May, 2014. All agronomic practices were kept normal and uniform for both treatments. Okra requires a long and warm climate and is susceptible to frost. The seed usually does not germinate when the temperature is below 20 ℃. The plants started emerging after 3-4 d and were apparently visible after one week.

However, after the crop germination, the plants were thinned out at 3-5 leaf, whereas the irrigation was applied to both treatments with an interval of 6-8 d. The water consumed by each furrow during irrigation was measured with cut-throat flume under both experimental treatments and recorded the reading of irrigation water depth (cm). While for measuring the plant growth of each treatment, randomly ten plants were selected and tagged, and plant height (cm), growth rate (cm) and a number of branched per plant were recorded, and then the average number was calculated respectively.

Fertilizers are one of the most important factors, which can increase crop yields. The chemical fertilizers were applied to all plots using recommended dose[30] that phosphorous (P) at the rate of 100 kg/acre (1 acre = 0.40 hm^2), potassium (K), 50 kg/acre, and nitrogen (N) as urea, 55 kg/acre. Thus on the basis of experimental plot size, 10 kg of P_2O_5 and 5 kg of K_2O were applied in both plots at sowing time, while 10 kg of N was applied 30 d later at pre-flowering stage. Okra is highly susceptible to a large range of insect pests and diseases for all growing areas[31]. During the vegetative growth stage, the crop was sprayed with Nitenpyramat at the rate of 200 mL/acre to kill the insects. The crop harvesting was mainly started in the first week of July, afterward okra pods were weighed separately and the yield data were converted into kg/hm^2 for experimental treatments.

2.5 Soil sampling

48 soil samples were taken from ridges with the help of auger sampler at different soil depths of 0-20 cm, 20-40 cm, 40-60 cm and 60-80 cm. These samples were collected from each treatment separately before sowing and after harvesting of the crop and placed in plastic bags. Two samples were also taken for the soil dry density from both treatments at depth of 0-20 cm with core sampler. These soil samples were examined for following parameters as presented in Table 1.

Table 1 Physico chemical properties of studied soil

S. No	Parameter	Adopted Method	For	Reference
1	Soil Texture	Bouyoucos hydrometer	Soil	[32]
2	Dry Density/pd	Core method	Soil	[33]
3	EC_e /dS·m^{-1}	Soil saturation extract	Soil	[34]
4	pH	Soil saturation extract	Soil	[34]

The flow rate was calculated using Equation (1), while the total required depth of water to be filled the furrows in each irrigation was measured by Equation (2) under both treatments[11].

$$Q_s = \frac{[C_s(h_u - h_d)n_f]}{[(-\log S)n_s]} \tag{1}$$

$$QT=AD \tag{2}$$

In this study water saving was measured with or without plastic sheet at furrow bottom, and then compared with traditional irrigation method. The irrigation water in all treatments was calculated by the Equation (3) and (4), whereas the irrigation data for flood irrigation practices was taken from the literature[8].

$$WS(\%) = \frac{(W_{FL} - W_{FP})}{W_{FL}} \times 100 \tag{3}$$

$$WS(\%) = \frac{(W_F - W_{FP})}{W_F} \times 100 \tag{4}$$

The total yield recorded from T_0 was compared to T_1 and these results were also compared with the results of flood irrigation method (from literature). Equation (5) and (6) were used for comparing the yield of okra crop.

$$Yield(\%) = \frac{(Y_{FL} - Y_{FP})}{Y_{FL}} \times 100 \tag{5}$$

$$Yield(\%) = \frac{(Y_F - Y_{FP})}{Y_F} \times 100 \tag{6}$$

3 Results

3.1 Physicochemical properties of soil

The soil samples were collected from different location of the each treatment plots at the depth of 0-80 cm and then the physical and chemical properties of soil were analyzed.

3.1.1 Texture of soil profile

The soil texture analysis revealed a non-significant variation of soil particles relative percentage at different depths, whereas the soil was loamy in texture according to the USDA Soil Taxonomy on depth of 0-80 cm under both treatment plots, which remained unchanged after the crop harvest.

3.1.2 Dry density of soil profile

The results of soil dry density (pd) for treatments T_0 and T_1 were presented in Table 2. It was indicated that the value of dry density was 1.23 g/cm^3 before sowing and increased to 1.24 g/cm^3 after harvest under T_0 at soil depths 0-20 cm. Whereas, it was 1.19 g/cm^3 before sowing and increased to 1.20 g/cm^3 after harvest under T_1 at soil depths 0-20 cm, however the ANOVA revealed that soil dry density was non-significantly (p>0.05) between both treatments.

3.1.3 pH and EC_e of soil profile

The soil pH and EC_e results data for both treatments (T_0 and T_1) were depicted in Table 4. The data of pH in pre-sowing were in range of 8.1 to 8.5, while for the post-harvest pH data are in the ranged from 7.8 to 8.3 for the treatments of T_0 and T_1 at the depths of 0-80 cm respectively. From the results of Table 4 showed that the pH of before crop sowing and harvest of T_0 and T_1 decreased at the soil depths from 0-80 cm respectively.

Table 2 Dry density for both treatments

Soil depth /cm	Before sowing/g·cm^{-3}		After-harvest/g·cm^{-3}	
	T_0	T_1	T_0	T_1
0-20	1.23	1.19	1.24	1.20

Table 3 ANOVA tests of between treatments

Source Variation	SS	DF	MS	F	P.
T_0	0.000	1	0.000	32.151	0.001
T_1	0.002	1	0.002	161.608	0.000
Depth	0.002	3	0.001	50.926	0.000
Error	0.000	6	0.000		

Table 4 PH and EC_e of soil profile for both treatments

S. No	Soil Depths /cm	Pre-sowing				Post-harvest			
		pH		EC_e /dS·m^{-1}		pH		EC_e /dS·m^{-1}	
		T_0	T_1	T_0	T_1	T_0	T_1	T_0	T_1
1	0-20	8.2	8.4	1.15	0.39	7.8	7.9	1.70	1.39
2	20-40	8.5	8.3	0.66	0.30	8.0	8.1	1.21	1.60
3	40-60	8.4	8.2	0.47	0.32	8.3	8.0	0.57	1.42
4	60-80	8.1	8.2	0.42	0.60	8.0	7.9	0.59	0.61

It was indicated that the values of EC_e were ranged from 0.30 dS/m to 1.15 dS/m pre-sowing and were noted in the range of 0.57 dS/m to 1.70 dS/m for the treatments T_0 and T_1 at the depths of 0-80 cm. The results from Table 4 showed that EC_e of soil saturation increased after harvest at the treatment T_1 at the soil depths of 0-80 cm, while the analysis of variance revealed that the EC_e of soil at different depths was significantly ($p<0.05$).

3.2 Crop growth and yield parameter

The plant heights and number of branches per plant were presented in Table 5. The analysis of variance showed that the plant heights and number of branches per plant for selected 10 different plants were significantly changed by using plastic sheet at furrow bottom. It was determined that the average values of plant height were noted 16.35 cm ($p<0.05$), 36.35 cm ($p<0.05$) and 47.10 cm ($p<0.05$) under treatment T_0 and 17.30 cm ($p<0.05$), 36.85 cm ($p<0.05$) and 51.10 cm ($p<0.05$) were recorded for the treatment T_1 on 3rd, 6th and 9th irrigation respectively.

Table 5 Plant heights and branches per plant for both treatments

Treatments	3rd Irrigation		6th Irrigation		9thirrigation	
	T_0	T_1	T_0	T_1	T_0	T_1
Plant height	16.3±1.26	17.3±1.50	36.3±1.78	36.8±1.66	47.1±2.18	51.1±3.72
Branches/plant	1.5±0.28	1.7±0.21	2.1±0.32	2.4±0.36	2.9±0.34	3.5±0.41

Note: ± is standard deviation.

Table 5 showed that the average number of branches per plant were recorded 1.59 cm, 2.15 cm and 2.9 cm of treatment T_0 and 1.68 cm, 2.41 cm and 3.55 cm of treatment T_1 on 3rd, 6th and 9th irrigation respectively. Figure 2 showed the results of okra pods yield, which was 8,332 kg/hm^2 of T_1 and 7,575 kg/hm^2 of T_0 respectively. It showed an increase in using of plastic sheet in furrow irrigation at T_1.

3.3 Irrigation duration, volume and water saving

The results for irrigation and time taken to fill each furrow strip at a required depth of 70% under both treatments were shown in Table 6. The applied irrigation water for each furrow of both treatments at every irrigation interval was calculated with cutthroat flume (Q=0.005 m^3/s). The total mean time taken by treatment T_1 during irrigation was recorded as 540 s, while for T_0 irrigation method it was 780 s. It was evident from the results that the total mean depth of irrigation water applied to each treatment block was 344.17 mm and 496.17 mm, while the volume of water applied was noted 21.56 m^3 and 31.09 m^3 for treatments T_1 and T_0 respectively (Table 7). However, during crop growing phase, a rainfall of 0.17 mm was measured, which was further added in the total depth of water consumed under both treatments.

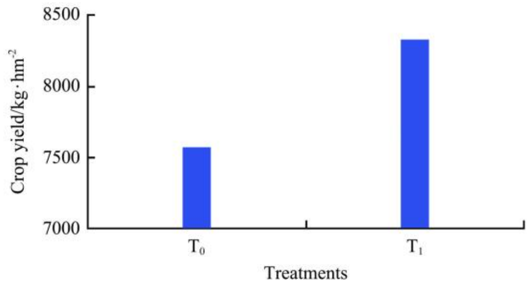

Figure 2 Crop yield for treatments T_0 and T_1

Table 6 Duration for irrigation application under both treatments

Number of irrigation	Area/m^2		Depth/mm		Time taken by each furrow/sec		Number of furrows		Total time /sec	
	T_0	T_1	T_0	T_1	T_0	T_1	T_0	T_1	T_0	T_1
08	62.7	62.7	62	43	130	90	6	6	780	540

Table 7 Volume of irrigation application for both treatments

Treatments	Recommended depth water	Rainfall	Total depth of water applied	Irrigated area/m^2	Volume of water used/m^3
T_0	500	0.17	496.17	66	31.09
T_1	500	0.17	344.17	66	21.56

The total crop water required by okra crop in entire growing period under without plastic cover furrow bottom irrigation method was 500 mm, while in the case of conventional flood irrigation methods it was 720 mm. The mean water saving was determined 52.22% and 31.00% of T_1 and T_0 respectively, while compared to the water saving of flood irrigation method. Also, water saving was 30.64% under T_1 as compared to that of T_0 (Table 8).

Table 8 Irrigation water saving for both treatments

Irrigation methods	Irrigation water	Water savings/%	
		Compared with flood Irrigation	Compared with T_0
T_0	496	31.0	-
T_1	344	52.2	30.6
Flood irrigation	720	-	-

4 Discussion

4.1 Impact of plastic sheet on physic chemical properties of soil

4.1.1 pH and EC_e of soil profile

Table 4 showed that the pH of soil profile slightly decreased with the depth in upper soil layer in both experimental treatments. The soil pH decreased after harvest under T_1. Decrease in pH was observed with respect to increasing EC_e under T_1, as the salts from upper to lower layer were not leaching down. It was observed that using plastic sheets laid on furrow bottom minimized the salts being leached. The EC_e of soil profile depth was shown in Table

4. EC_e slightly increased under T_0, but in the case for T_1, there wasn't any increase observed. The reason behind was plastic sheet which stopped the infiltration from furrow bottom and diverted the downward movement of water to the sides of furrow ridge, leaving all soluble salts there. Similar study has been conducted[35] to observe the impact of plastic treatment on the soil hydraulic conductivity and chemical properties.

4.1.2 Dry density of soil profile

After the crop harvest, the mean soil dry density was increased 0.01 g/cm^3 under both treatments. These results of the experiment are matching to those reported by [36] and [37]. In upper soil layer the dry density of soil might increase with the preparation of surface layer crust, existing of sodium content with the dispersion of the clay soil with the consequent formation of fine pores.

4.2 Plant height, number of branches per plant and crop yield

Table 5 showed that the plant height and number of branches plant^{-1} under treatment T_0 were less than as compared to those under treatment T_1. The increase in plant height and number of branches plant^{-1} under T_1 might be due to more availability of soil moisture in the root zone and better nutrient use efficiency and their uptake by plants. The soluble nutrients might have not leached down due to zero infiltration rates below the furrow bottom, which was because the usage of plastic sheet provided the maximum opportunity for improving water and nutrient use efficiency for plants sown on ridges. Therefore, the plants sown on ridges under treatment T_1 resulted in well developed root system, better growth, and higher plant height as compared to T_0. Under treatment T_0, excessive amount of water and soluble nutrients were washed out due to infiltration from furrow bottom, which might be the reason for poor plant growth. These results are supported by [38] who reported better root growth, plant height, fruit weight, nutrient uptake and yield in furrow method although there was non-significant effect between different sowing methods either on ridge or furrow on root growth. These results are similar to the previous study[38] that they concluded the plastic sheet resulted in maximum plant height, earlier flower emergence, and the highest number of flower spikes per plant, floret per spike and flowers per plant. Additionally, these results are fully favored by [39] who reported plant height, the number of primary branches, the number of leaves and yield were better under plastic sheet mulched treatment as compared to those of control.

The performance overall was found to be the best in treatment T_1 under furrow irrigation method using plastic sheets below furrow bottom (Figure 2). This may be due to availability of more soil moisture and soluble nutrients in the root zone where plastic sheets under furrow bottom were used, facilitating it to uptake and stopping leaching. Hence, it created better conditions for the growth and a well development of plant root system. Whereas because of leaching of sufficient amount of soluble nutrients, the yield for T_0 was observed to be less as compared to that of T_1. These results are supported by [40] which stated that the higher crop production with furrow irrigation method, it might be the reason that more phosphorus (P) contents in the leaves, roots, and grains in furrow sown crop. The same results have also been stated by [38], which reported better yield harvested with furrow irrigation. These results are supported by [41], which studied the effect of plastic mulching and reported good effects on growth, yield and weed suppression. These results are also favored by [2] which reported better effects of mulch treatments on yield and yield ingredients. And the experimental results are fully supported by [42] who applied colored plastic sheet and row covers and found better effects on the growth and yield of okra.

4.3 Irrigation water volume and duration

Table 7 showed the volume of irrigation water applied during the field study for the treatments T_0 and T_1 for growing okra crop. Irrigation water also included the amount of seasonal rainfall in volume of water used during the study. The total average time taken by treatment T_1 during irrigation to irrigate all the furrows to 70% of depth of furrow was less as compared to that byT_0. The time of irrigation application was reduced due to plastic sheet which stopped the infiltration rate, allowing it consume less amount of water as compared to T_0. Under T_0 treatment, due to infiltration a large amount of water was being wasted and irrigation time increased. The results are matching with the findings[43], which were reported that the sandy loam soil cause the low WUE with the excessive irrigation, deep percolation of the irrigation water and shortage of water in the critical stage of the crop. These results are similar to the results of [38], who concluded that in the management of soil, the use of mulch as protective cover placed over the soil could prevent water content, improve seed germination, deliver nutrients, and minimize the development of weeds. These outcomes are associated to[41], who reported better effects of plastic mulching on soil temperature, infiltration, and minimum water content losses under field conditions.

4.4 Water saving

Water saving (%) for treatments T_0 and T_1 under the field experimental study was showed in Table 8, and was compared with each other and flood irrigation method for okra crop. Results are in agreements with the findings by [12], who reported that vertical infiltration from the furrow decreased with the using of plastic sheet on furrow bottom and increased the water saving efficiency of furrow irrigation practice. Similar results have also been reported by [28], who stated that 22.73% to 40.38% increase in water saving efficiency with the use of plastic sheet as mulching in furrow irrigation method. These results are similar to those given by [44], who reported the WUE with plastic film was 2%-61% higher than non-plastic mulch. These results are also favored by [4], who reported that plastic mulched furrow increased 22.73% to 40.38% of saved water and the water saving efficiencies when compared to those of un-mulched (control) under furrow irrigation method.

5 Conclusions

The "Furrow irrigation method" is considered as an effective conventional irrigation practice, which is appropriate in regions where fresh water sources are limited. In this experimental study under furrow irrigation method it showed better performance with using of plastic sheet in associate with crop production and water saving.

Based on the study it was concluded that the use of plastic sheet in furrow irrigation practice has a slight effect on physicochemical properties in the soil profile at a depth of 0-80, while the mean pH of soil decreased and soil salinity (EC_o) increased under both treatments (T_0 and T_1) after harvesting. However, the yield was higher under T_1 (8,332 kg/hm^2) as compared to that under T_0 (7,575 kg/hm^2), while the saving of water was determined 31.00% and 52.22% under T_0 and T_1 respectively. Moreover, future research study may be conducted on different soils types under different crops in the regards with water saving and crop production under the use of plastic sheet at furrow bottom.

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