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Assessment of Groundwater Quality and Soil Salinity/Status Under Various Irrigation Systems in Arid Region of Jamshoro District

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Abstract. The agricultural lands are being affected due to groundwater (GW) quality issues. To address this worldwide problematic situation, various irrigation studies have been practiced to identify the effects on the soil conditions. The current study has been designed to assess the GW quality and soil salinity/sodicity by different irrigation techniques in the remote mountainous area of Jamshoro district at Gul Muhammad Khaskheli farm Thana Boula Khan. The experimental plot was designed under furrow, pitcher and poly ethylene bag irrigation system. These soil characteristics indicated that the drain-ability of the soil was high, with an infiltration rate of 1.60 cm/h and water holding capacity was low. Water samples were collected at each irrigation time from sowing to harvest. The soil understudy was non-saline (ECe < 4.0 dS/m) and non-sodic (pH < 8.0, SAR < 7.5 and ESP < 15.0) before crop sowing in all the three methods of irrigation at all the three sampling depths, i.e., 0-15 cm, 15-30 cm and 30-60 cm. Thus, the quality of water used for cultivation of ladyfinger/Okra crop under all irrigation methods was Class-I quality water.The investigated results shown that ECw (electrical conductivity of water) was < 1.5 dS/m, pH < 8.0, SAR (sodium adsorption ratio) < 10.0 and RSC (residual sodium carbonate) were non detective. After crop harvest changed a little bit, change was observed in the soil, i.e., under furrow and pitcher irrigation method, the ECe, SAR. and ESP (exchangeable sodium percentage) decreased in the wetted zone and increased at the wetted periphery. Under the polyethylene bag irrigation method, ECe, SAR and ESP decreased at depths 0-15 cm and 15-30 cm but these increased at lower depth, i.e., 30-60 cm after crop harvest. However, the soil remained non-saline and non-sodic.

Keywords: water quality, soil salinity, pitcher, transparent plastic bags, lady finger /Okra crop

Introduction

Groundwater (GW) is about 20% of the world's resources of freshwater and is used in large amounts for irrigation, industry and domestic activities. However, GW quality in most of the 3rd world countries, including the sub-continent is rapidly deteriorating (Kuchekar *et al*., 2009). The qualitative assessment reported by Nikolaou (2020), shown the use of GW needs a particular cure during the irrigation due to salt hazard and toxicity of specific ions having adverse effects on the physical properties of soil and the sensitivity of crops (Colombani, 2020).

In Pakistan, groundwater contributes a considerable portion for freshwater resources Kahlown *et al*. (2006). The GW resources are used as supplement irrigation in the canal command area, while in the arid regions, most of the agriculture depending on the GW resources. The country has an arid and semi-arid climate. Apart from a variety of other reasons for low crop productivities, the deteriorating quality of groundwater has adverse effects on soil structure and hence reduced soil fertility (Chaudhry *et al*., 2005).

Kahlown *et al*. (2006) revealed that in Pakistan, degraded water quality severely effects on agriculture and human consumptions. Similarly, Cowasjee (2007) reported that about 30% of the groundwater is being pumped out in the Indus basin and useful for drinking and agriculture purposes, while the rest of 70% of tube wells are pumping saline water. The contaminated water might be highly hazardous to the soil, creating problems like soil salinity and sodicity, consequently decreasing the percolation process in that soils. Yunas *et al*. (2015) researched water quality for three years in Tehsil Attock, Pakistan. They have collected some 122 groundwater samples, while revealed that 43% of water samples were found fit, 13% marginal quality and 44% were diagnosed unfit for the irrigation purpose. The ground-

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water samples were shown Ec ranged 0.05-8.1 dS/m, Ca and Mg 0.6-70 meq/L, Na 0-40.6 meq/L, CO_3 0-0.04 meq/L, HCO_3 0.5-15 meq/L, Cl 0.2-70 meq/L, SAR 0- 49.85 and RSC 0-13 meq/L. Tahir in (1994) reported that in Sindh province, there is a lack of water quality monitoring and information management system, which has increased secondary soil salinization. Hence, the groundwater quality used for agriculture and livelihood chores is not suitable according to need. The improvement in condition requires analytical measurements before using GW for crop production and human consumption.

Today, the over exploitation of groundwater created qualitative concerns. GW is one of the significant solitary sources of agriculture and drinking purpose (Adimalla *et al*., 2020; Nikolaou *et al*., 2020) in the arid region of Sindh province. These problems are more in the arid regions, that totally depends on the use of GW resources for agricultural and livelihood chores (Sabzevari *et al*., 2020).

Over pumping and lack of management (Shaji *et al*., 2007) are the major threats to food security. To mitigate these challenges is possible with the sustainable management of precious groundwater resources (Al-abadi and Al-Shamma'a, 2014; Alcamo *et al*., 2007).

Soil is a natural and potential asset for crop life, similarly, water is a vital constituent to continue this system. Healthy soil provides some vital functions, including, ability to accumulate the water, control the movement of water and counter balance contaminants (Jeff, 2001). The GW of medium to high SAR reduces collective constancy, increases the bulk density of soil, and decreases the percolation process (Emdad *et al*., 2006).

By addressing this issue, a research study has been designed to assess the GW quality impacts on soil salinity/sodicity rank by different Irrigation techniques Systems.

Materials and Methods

The study area. The experimental farm of Gul Muhammad, situated at northwest of Thana Boula Khan (TBK), district Jamshoro (Sindh) (Fig. 1). The study area is the mountainous region of Sindh province, due to high elevation, agriculture is not possible on canal irrigation system (Memon *et al*., 2010). The area of study is entirely an arid region and specific irrigation methods are applied for agriculture cultivation. Among various conventional and non-conventional irrigation systems, pitcher, transparent plastic bag, and furrow irrigation are getting popularity for growing vegetable crops in arid regions due to water scarcity.

The experiment on three irrigation methods i.e. furrow, pitcher and transparent plastic bag (Fig. 2) was conducted during the rabi season (winter-cropping season).

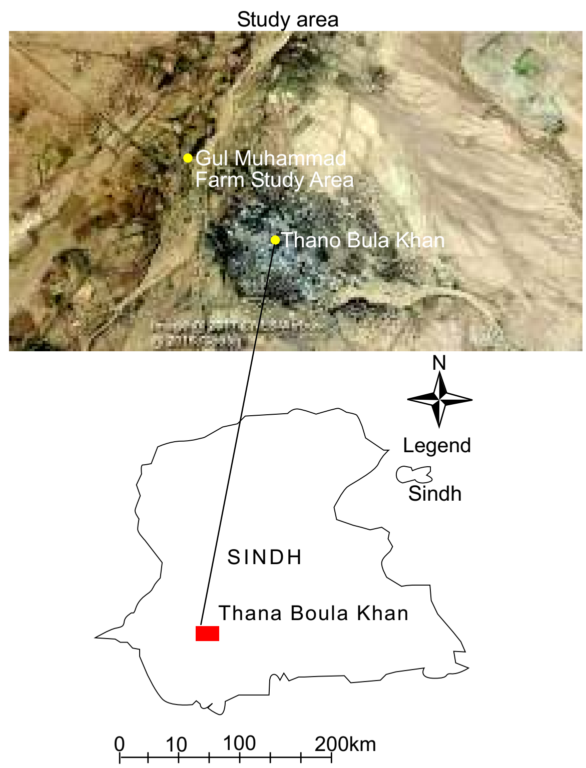

Fig. 1. Study area.

Fig. 2. Experimental overview of pitcher, polyethylene bags and furrow irrigation systems.

Soils. ***The research area's soils are alluvial.*** They are typical silty sand soils with coarser layers of conglomerates (sand, pebbles, and boulders) soils, hard and compact lime and sandstones. The loess (windblown) silt and fine sand are also traced in the piedmont and cover flood plains. The texture is slightly coarse with approximately bout 50% sand. Therefore, it is known as the spate irrigated area in the region. The GW is replenished immediately after the precipitation by which a limited area is cultivated through dug and deep wells and Persian wheels besides spate irrigation (Memon *et al*., 2010).

Cropping pattern. The major crops of wheat, barley, sorghum, sesame, melons, jujube, onion and other seasonal vegetables are grown in the area by following indigenous techniques of irrigation like flood and furrow due to which about 30 to 40% of water is being wasted (Memon *et al*., 2010).

Application and design of irrigation systems. ***Pitcher irrigation system.*** Pitcher irrigation is lowest, small-scale irrigation technique used in remote regions. The technique contains burial clay containers buried into the soil upto the neck and filled with water. This allows the moisture through their walls and collected on the soil to moist the seed to start the natural growth process. The pitcher was maintained as well manually. Pitcher irrigation may be utilized on the small-scale for those areas, where water is in shortage and in remote areas where vegetables are expensive and hard to come (Barthwal, 2005).

Polyethylene bag irrigation system. The polyethylene shopper bags are also used for irrigation purposes, which is the most basic and water-saving method. Mostly used in the water-frightened and remote areas. The vegetable plants are cultivated in the appropriate size of white plastic shopper bags. The shopper filled with soil and few holes may be developed in the sides and bottom of the shopper bag for the aeration purpose and to control the salts accumulated through the irrigation. Thereafter, filled with water as irrigation manually. (Memon *et al*., 2010).

Furrow irrigation system. The furrow irrigation method is an indigenous technique being practiced for a long time. Mostly this technique of cultivation is known as the row crop method under which is the most of the crops might be irrigated except those grown in ponded water. The corp can be irrigated using the furrow technique of harvesting by adopting the proper furrow spacing, the grade of land and size of the experiment. The furrow technique requires the type of crop and size of the occupied land for the irrigation method reported by (Memon *et al*., 2010).

Soil analysis. ***Soil characteristics.*** The determination of soil characteristics, i.e., texture, field capacity (FC) and wilting point (WP), composite soil samples upto a depth of 60 cm collected from the experimental site, whereas intake rate (IR) and dry bulk density (DBD) were determined in the field.

Soil sampling for assessment of salinity/sodicity status. For the evaluation of salinity/sodicity parameters, the soil samples from three methods of irrigations i.e. furrow, polyethylene bag and pitcher collected before and after crop harvest at depth from 0 to 60 cm, with an interval of 15 cm. The soil samples collected for the determination of texture, FC, WP and salinity/sodicity appraisal, were sent for analysis to the Laboratory of Pakistan Council of Research in Water Resources (PCRWR), (old name Drainage Reclamation Centre Laboratory) Tandojam.

Infiltration rate. US Salinity Laboratory staff gives the infiltration rate (IR) of the soil determined as per procedure (Richards, 1954). For this purpose, a double ring infiltro-meter was used to test the infiltration rate of the soil. The iron rings contain an outer ring of 35.56 cm and an inner ring of 27.94 cm in diameter with a height of 40.64 cm was used. The outer ring of 35.56 cm diameter was driven in the soil upto a depth of 20.32 cm. Then, the inner ring of 27.94 cm diameter was driven in the soil in the center of the first ring at the same bottom level as that of the first ring. After that, water was filled in the second ring upto 15.24 cm depth. A staff gauge was fixed in the center to note the water depth heights. To avoid evapouration, a few drops of oil are put on the surface of the water. The readings from the staff gauge noted after every 5 min of upto 7 h. By averaging the readings (depth of water) and dividing it by time, the infiltration or intake rate of the soil is expressed as cm/h.

Dry bulk density. To estimate the dry bulk density (DBD) of the soil, core soil samples of known volume (100 cm^3) were taken from the soil at depth from 0 to 60 cm, with an interval of 15 cm. These core soil samples were put in an electric oven for 24 h at 105 °C for drying in a desiccator and weighed after cooling in desicator.

Irrigation application. Since the furrow irrigation method is a traditional method of irrigation; therefore, irrigation is applied at a frequency of 4-8 days based on physical observation of the soil and crop. The irrigation water applied under this method of irrigation was 75 mm in each furrow at each time, which was measured using a Cut throat flume and recorded, whereas under the pitcher irrigation method, the water replenished at a frequency of 3-4 days. The water was replaced in the pitchers recorded in liters. Similarly, the irrigation water applied to polyethylene bags is also recorded in liters.

However, a tensiometer in each row of polyethylene bags was installed at a depth of 30 cm. When it indicated a tension near the wilting point, the irrigation was applied at 75 mm depth of each polyethylene bag and the volume of water used recorded.

Irrigation water quality. The irrigation of the Okra crop, groundwater of a dug well available at this farm used in all the three methods of irrigation under study. Since water quality is essential from an irrigation point of view as marginal or hazardous quality groundwater could pose a severe problem to the soil as well to crop, therefore to know the quality/class of dug well water used for irrigation under this study, periodic water samples collected for laboratory analysis. A number of 4 water samples were collected and got investigated from the PCRWR laboratory for these parameters, i.e. ECw, pH, SAR, RSC.

Results and Discussion

Soil characteristics. The compound soil samples collected from the field under study at depth from 0 to 60 cm, with an interval of 15 cm analyzed in the laboratory for texture, Field Capacity (FC), Wilting Point (WP) and Dry Bulk Density (DBD) parameters. While, the percolation rate of the soil was examined in the field. The soil characteristics are presented in Table 1.

Table 1 reveals that the texture of the soil was sandy loam (coarse texture). The field capacity was low, which ranged from 14.5% to 14.7% at three sampling depths. Thus, the available moisture (A.M) on an average was 8.4% only. Likewise, the infiltration rate was high, i.e., 1.60 cm/h, indicating the excessive drainability of the soil. The dry bulk density was somewhat higher than average soils. Since the soil of the study area was not alluvial but was the out-wash material deposited in the foothills. Such soils are called 'Piedmont soils. Such soils are usually characterized as low in the water holding capacity and high in drainability. The analytical results of this soil are a little bit more or less in agreement with those found by Memon *et al*. (2010), who worked for similar types of soils.

Irrigation water quality. The quality of irrigation water used for crop cultivation is very important, which determines the salt or exchangeable sodium accumulation in the soil profile, particularly in the absence of drainage conditions. Marginal or hazardous quality of irrigation water is used for crop cultivation under normal circumstances can pose severe problems like salinity/sodicity creation in the soil profile and reduce crop production to a considerable extent. However, marginal or hazardous quality irrigation waters could be used for certain kinds of crops and forest and fruit plant species under particular soil and water management conditions.

Table 1. Soil characteristics

Sampling depth (cm)	D.B.D (g/cm^3)	FC (%)	WP (%)	A.M (%)	Soil separates (%)			Textural class	Infiltration rate (cm/h)
					Sand	Silt	Clay		
0-15	1.58	14.6	6.4	8.6	60	25	15	Sandy loam	1.60
15-30	1.62	14.5	6.7	8.3	65	22	13	Sandy loam	
30-60	1.60	14.7	6.5	8.4	66	18	16	Sandy loam	
Average	1.60	14.6	6.5	8.4	63.6	21.7	14.7	Sandy loam	1.60

D.B.D = Dry bulk density; FC = Field capacity; WP = Wilting point; A.M = Available moisture.

Water samples were collected periodically and analyzed for ECw, pH, SAR and RSC parameters. The investigative consequences of the samples remain presented in Table 2.

The analytical results of the above 4 water samples indicate that ECw is < 1.5 dS/m, pH < 8.0, SAR < 10.0, and RSC are zero in all the samples. Thus, the quality of irrigation water used for the cultivation of Okra crops under three irrigation methods was useable, i.e., Class-I quality water.

Soil salinity/sodicity assessment. Soil salinity/sodicity mentions the exchangeable sodium available in the soil to such an extent, which disturbs the plant development harmfully. Thereby, also the crop yields were decreased to a considerable level. The cause of soil salinity/sodicity is usually due to parent material, shallow saline groundwater and the usage of hazardous quality water for irrigation. However, the justified irrigation of marginal to unfit irrigation water was communicated to the stakeholders for the cultivation of various fruit and vegetable as recommended by Yunas *et al*. (2015) in their study conducted for the irrigation water quality. Soil salinity or sodicity is one of the characteristics of arid and semi-arid climatical zones. Under arid or semi-arid conditions, the precipitation is scanty and unevenly distributed, whereas due to high temperatures and dry winds, the rate of evapo-transpiration increases. The soluble salts move the water surface upward through capillary action. Subsequently, water evapourates, leaving behind the salts on the ground surface and in the soil profile. Thus salinity is developed in the soil. When there is rain or irrigation, the sodium salts are hydrolyzed creating Na+ OH- ions which increase the pH of the soil, as well as sodium ions (Na+) are adsorbed by the soil particles, thereby the soil become sodic. The hazardous quality waters possess a high quantity of soluble salts (ECw > 3.0 dS/m) or SAR> 18.0 or both, thus creating saline/saline-sodic soils. Thus, to examine the variation in soil salinity/sodicity status of the soil under the applied three irrigation techniques, composite soil samples were drawn up to a depth of 60 cm before sowing and after harvest of the crop. These soil samples were got analyzed from the PCRWR laboratory at Tandojam. The analytical results of these samples are presented separately for each method of irrigation in Tables 3-5. The same type of study was conducted on the hydroponic research, in the glasshouse in the Faisalabad University of Agriculture. The evaluation and comparative efficiency of calcium and potassium ions tested in various maize varieties by mixing the salinity. The study was conducted on various levels of salinity under 100 mM of sodium chloride stress.

The results revealed that the poor growth of the plant, the salinity affected the plant's physiological structures (Suhaib *et al*., 2020).

ECe. Table 3 indicates that before the sowing of the Okra crop in the pitcher irrigation method, ECe ranged from 2.4 to 2.7 dS/m at three subsequent depths, showing that soil was non-saline (ECe < 4.0 dS/m. After the harvest of the crop, it ranged from 1.2 to 1.9 dS/m at the wetted zone (WZ). Though, at the wetted periphery (junction of the dry and wetting front), it ranged from 3.2 to 3.8 dS/m. Thus, indicating that ECe decreased in the wetting zone, whereas it increased at the wetted periphery at all the three sampling depths. This was because soil moisture pushed the salts from the wetted zone to the dry zone around the pitchers. Nevertheless, the soil remains non-saline (ECe < 4.0 dS/m). The same trend was also noted under the furrow method of irrigation, as presented in Table 4.

Under the polyethylene bag method of irrigation, the ECe at depths 0-15, 15-30 and 30-60 cm before crop sowing was 2.5, 2.1 and 2.3 dS/m, which after crop harvest, decreased to 1.9, 1.6 and increased to 2.6 dS/m,

Table 2. Analytical results of water samples

Sampling date		Parameters			
	ECw (dS/m)	pH	SAR	RSC	Quality class
01.04.2008	1.4	7.2	1.8	Nil	Useable C-I
30.04.2008	1.2	7.2	1.6	Nil	Useable C-I
26.05.2008	1.2	7.3	1.9	Nil	Useable C-I
19.06.2008	1.3	7.3	1.8	Nil	Useable C-I

*C-1 = Class-1; ECw = Electrical conductivity of water; pH = Concentration of hydrogen ions; SAR = Sodium adsorption Ratio; RSC = Residual sodium carbonate.

Table 3. ECe, pH, SAR, and ESP values of soil samples before and after harvest of the crop under the Pitcher irrigation method

Sampling	ECe (dS/m)			pH			SAR			ESP		
depth	B	A		B	A		B	A		B	A	
(cm)		WZ	WP		WZ	WP		WZ	WP		WZ	WP
0-15	2.6	1.3	3.2	7.3	7.2	7.2	3.3	3.1	3.4	4.6	4.2	4.8
15-30	2.7	1.2	3.6	7.3	7.2	7.3	3.3	3.0	3.4	4.1	4.0	4.6
30-60	2.4	1.9	3.8	7.2	7.2	7.3	2.9	3.0	3.6	4.3	4.3	4.6

B = Before crop sowing; A = After crop harvest; WZ = Wetted zone; WP = Wetted periphery; EC = Electrical conductivity; ESP = Exchangeable sodium percentage.

Table 4. ECe, pH, SAR, and ESP values of soil samples before and after harvest of the crop under the Furrow irrigation method

Sampling	ECe (dS/m)			pH			SAR			ESP		
depth	B	A		B	A		B	A		B	A	
(cm)		FB	RB		FB	RB		FB	RB		FB	RB
0-15	2.3	1.1	2.6	7.2	7.1	7.2	2.9	2.6	3.1	4.3	4.0	4.6
15-30	1.9	1.3	2.2	7.2	7.2	7.2	2.7	2.4	3.1	4.3	4.1	4.8
30-60	2.4	1.2	2.9	7.3	7.2	7.3	2.6	2.5	3.2	4.8	4.9	4.9

B = Before crop sowing; A = After crop harvest; FB = Furrow bed; RB = Raised bed.

respectively. Thus from the upper two depths, i.e., 0-15 cm and 15-30 cm, the ECe decreased, whereas at depth 30-60 cm, it increased a little bit after harvest of the crop. It might be due to the reason that is the soil, coarse texture in nature (sandy loam), the salts from the upper two layers leached down because of irrigation application and accumulated in the third layer (30-60 cm). However, the soil earlier crop sowing and subsequent harvest of the crop persisted non-saline (ECe < 4.0 dS/m) as showed by the investigative results of soil samples presented in Table 5.

pH. The pH of a soil solution indicates sodicity/alkalinity or acidity. The neutral value of pH is 7.0. If it increases above 7.0 values, the solution is said to be sodic or alkaline and if it decreases below the value of 7.0, it indicates the acidity of the solution. However, the intensity of sodicity or acidity depends upon the presence of OH or H ions in the solution. More the OH ions are increasing the sodicity value and if more are the H ions, increasing the acidity value of a solution. The pH of soil plays an essential role in taking the plant nutrients. A soil pH of 6.0 to 6.5 is considered the best value for maximum uptake of the nutrients by the plants. However, the soil pH values below 8.0 do not affect the plant growth (Richards, 1954).

Table 5. ECe, pH, SAR, and ESP values of soil samples before and after harvest of the crop under the Polyethylene bag irrigation method

Sampling	ECe (dS/m)		pH		SAR		ESP	
depth (cm)	B	A	B	A	B	A	B	A
0-15	2.5	1.9	7.2	7.1	2.5	2.3	4.5	4.3
15-30	2.1	1.6	7.2	7.1	2.3	2.4	4.5	4.4
30-60	2.3	2.6	7.2	7.2	2.7	2.9	4.8	4.9

B = Before sowing of the crop; A = After harvesting of the crop.

The pH of the soil under three irrigation methods at all the three sampling depths ranged from 7.1 to 7.3 before crop sowing and after crop harvest as presented in Tables 3-5, respectively. Thus, no remarkable change was observed in pH values after crop harvest as compared to the values before crop sowing. Consequently, the pH values remained under safe limits in all the three systems of irrigation before and after the harvest of the crop.

SAR. Sodium adsorption ratio (SAR) may be defined as the ratio between calcium (Ca^{+}), Magnesium (Mg^{+}) and Sodium (Na^{+}). The SAR values either of soils or irrigation waters beyond allowable limits affect the plant growth and soil, respectively. SAR values in soils above 7.0 to 7.5 affect the plant growth adversely, whereas the SAR values of irrigation waters above 10.0 affect the plant growth and the soils are liable to become sodic, particularly under restricted drainage conditions.

Tables 3-5 indicate the values of SAR of soil samples at depth from 0 to 60 cm, with an interval of 15 cm under pitcher, furrow and polyethylene bag methods of irrigation before and after harvest of Okra crop, respectively. Under the pitcher irrigation method, the SAR values before crop sowing ranged from 2.9 to 3.3 at all three sampling depths. After the harvest of the crop, it reduced slightly in the wetted zone (WZ) but improved somewhat at the wetted periphery (WP) at all three sampling depths, as presented in Table 3. The same trend were observed in-furrow and polyethylene bag methods of irrigation understudy, as shown in Tables 4-5, respectively, due to the spread of moisture and remains salts after each irrigation in the peripheral zone of the plant, while mixing with soil contents without the additional flow of water. So, the salts rain in the periphery zone and detected SAR slightly in the wetting periphery. However, all the SAR values of the soil samples earlier and later the harvest of the crop is the three methods of irrigation indicate that the soil was non-sodic (SAR < 7.0).

ESP. Exchangeable sodium percentage (ESP), likewise SAR, represents the intensity of sodicity/alkalinity of the soil. If values of ESP are less than 15.0, the soil is considered to be non-sodic or non-alkaline; whereas if the values of ESP are more than 15.0, the soil is said to be sodic or alkaline. However, the amount of exchangeable sodium present in the soil determines the intensity of sodicity.

Likewise SAR values of the soil samples, the ESP values showed the same trend at all the three sampling depths, i.e. 0-15, 15-30 and 30-60 cm under all the three methods of irrigation, i.e. pitcher, furrow and polyethylene bag before and after harvest of Okra crop, respectively.

Since, all the ESP values at all the sampling depths, under three methods of irrigation are far below 15.0 as presented in Tables 3-5, therefore the soil was non-sodic before and after harvest of the Okra crop.

Conclusion

The soil conditions have been changed a little bit under the furrow and pitcher irrigation system, where the water consumption was more than the third irrigation system of polytheline begs. Water was ponded in the furrows and slowly seeped laterally into the soil, and the same pattern observed in the pitcher irrigation system that water flowed and percolated into the soil directly, The ECe, S.A.R. and ESP decreased in the wetted zone and increased at the wetted periphery, while the water was applied into the polythene begs not fully saturated nor remains on the dry level. The begs were already filled with soil, while the excessive moisture little bit seeped through the holes from polythene begs, otherwise, the moisture was slowly dried into the soil. So, a little bit of change was observed in furrow and pitcher irrigation system. The ECe, S.A.R., and ESP decreased at depth from 0 to 30 cm, with an interval of 15 cm. but these increased at a deeper depth, like 30-60 cm after crop harvest, it is revealed, that soil did not contain the slaine/sodic. In the study area under all the irrigation methods.

Suggestions. It is suggested that pitcher and furrow irrigation systems may be applied to cultivate vegetables in arid regions because their effect on the soil is not adverse. At the same time, the benefits are too high, while the crops are harvested under arid regions.

Conflict of Interest. The authors declare no conflict of interest.

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