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RESEARCH ARTICLE

THE EFFECT OF WATER QUALITY AND DIFFERENT DRIP IRRIGATION SYSTEMS ON POTATO GROWTH, YIELD AND WATER USE EFFICIENCY

[(1)]Yousef Abdulaziz Almolhem

(1)Department of Environmental and Natural Resources , College of Agriculture & Food Science, King Faisal University, P.O. Box 420, Al-Hassa 31982, Saudi Arabia.

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E-mail:
yalmolhem@kfu.edu.sa

Abstract

Potato yield response to different water quality and subsurface drip irrigation is the major importance in production planning where water resources are limited. This study aims to determine the effect of different water qualities and different drip irrigation systems on potato growth, yield, and water use efficiency in the El-Hasa Region, KSA, during growing seasons2010 and 2011. Potato was grown under drip surface and subsurface drip irrigation systems. The main factors of this study were two irrigation water sources (Fresh & Treated waste water) and the treatments of drip irrigation systems Drip irrigation surface (DIS), Drip irrigation subsurface 10 cm depth (DISS10) and Drip irrigation subsurface 25 cm depth (DISS25). The increases in number of plants per square meter, under fresh water in season 2011 were 3.5, 3.2 and 5.3 %. Whereas under treated wastewater were 2.7, 3.6 and 4.0 % in comparison with season 2010 under DIS, DISS10, and DISS25, respectively.The increases in branches number under fresh water in season 2011 compared by season 2010 were 2.9, 2.8 and 2.7 %. Whereas under treated wastewater were 2.6, 2.6 and 7.1 % in comparison with season 2011 under DIS, $DISS_{10}$, and $DISS_{25}$, respectively.The increase in mean of plant length (cm) were 0.4 % in season 2011 when compared byseason 2010. The data shows that increase in season 2011 relative to season 2010 for potato yield was maximum under fresh water and DISS25(3.5%), followed by DISS10 (2.2%), while the minimum percentage of increase in potato yield (0.9%) when using DIS. On the other hand under treated wastewater values of increase percentage were 6.9, 2.3 and 0.9% under DISS25, DISS10 and DIS, respectively. The increase in WUE in season 2011 relative to season 2010 in both Fresh and Treated wastewater were (2.9, 1.8; 0.8 % and 2.3, 1.3; 0.8 %), respectively.

Introduction

Drip irrigation sub-surface system (DISS) consists of emitters, which are either buried or placed on the soil surface for discharging water at a controlled rate. All micro irrigation systems have the potential to be very efficient in irrigation water conveyance, control and application. Drip irrigation system should apply water with high uniformly so that each part of the irrigated area receives same amount of water. Insufficient water leads to high soil moisture tension, plant stress and reduced crop yields. Excess water may also reduce crop yields below potential levels due to leaching of applied nutrients, increased disease incidence or failure to stimulate growth of the commercially valuable parts of the plant (**Solomon, 1993).**He reported that in DISS, irrigation water and injected fertilizers are supplied directly to the roots of crop. This is especially advantages in case of nutrients added those have low mobility into soil. He add that in DISS, top 20.0 cm of soil have lower soil water content when laterals are buried at 45.0 cm soil depth, resulting in reduced evaporation. DISS is the most advanced method of irrigation, which enables the application of the small amounts of water to the soil through the drippers placed below the soil surface with discharge rates generally in the same range as surface drip irrigation **(ASAE Std., 1999).** DISS offers many advantages over the surface drip irrigation such as reduction in evaporation and deep percolation losses and elimination of surface runoff **(Camp, 1998).** Water infiltration in the DISS takes place in the region directly around the dripper, which is small compared with the total soil volume of irrigated field. A subsurface dripper usually forms a small cavity around it into which water can freely flow **(Shani and Or, 1995)**. Uptake of water by plant roots causes soil drying and subsequent increased soil water tension. Selected drippers discharge should not exceed the root uptake rate **(Clothier and Green, 1997; Lazarovitch, 2001).**

Smajstrla et al. (2000) compared automated controlled DISS irrigation with the conventional semi-closed seepage sub-irrigation in Florida. The conventional irrigation system is under criticism because of surface runoff and nutrient contamination of adjoining waterways. The DISS system required more electrical energy but used 36% less water to obtain the same potato yield.**Steyn et al. (2000)** examined irrigation-scheduling options for drip-irrigated potatoes.**Ruskin (2000)** reported that DISS system could be used to apply water in small amounts and at higher frequency. He achieved a saving of 46% of water in comparison to surface drip in medium and heavy textured soil in which the water movement occurred mainly due to capillary forces. **Lamm and Trooien (2003)** found that corn yield was the highest under DISS at irrigation level of 75% crop evapotranspiration. He also studied the environmental impact of DISS in silt clay soil when drip tubes were placed at 30.0 cm below the soil surface. It was observed that soil water remained at the root zone for utilization of plants and was not lost due to deep percolation.

Simone et al. (2002) showed that drip irrigation had potential as an economically viable potato production method in the southeastern United States. Optimized irrigation rates were 99% to 86% of the water called for in their irrigation model. **Zartman et al. (1992)** examined tape depth and emitter spacing on tuber yield and grade of Norgold Russet potato in Lubbock, Texas. Tape depth or emitter spacing did not influence potato yield, but the proportion of misshaped tubers was greater when the tape was buried at 0.2 m than with shallower placement. Soil temperature was greater with the tape at 0.2 m than at 0.1 m or 0.025 m. **DeTar et al. (1996)** found that tape depths of 0.08 m (above the seed piece) and 0.46 m (below the seed piece) performed better than intermediate and greater depths. **Fabeiro et al. (2001)** used 10 drip irrigation treatments to examine the effect of the timing of irrigation deficits on potato yield and water use efficiency in Spain. Irrigation deficits occurring during mid- and late-season tuber bulking were particularly damaging to yield. High yield was combined with high water use efficiency when irrigation deficits were restricted to early in the season.

The objectives of the current study is determine the effect of fresh and wastewater and different surface and subsurface drip irrigation systems on vegetative growth, yield and WUE of potato through two successful seasons 2010 and 2011.

Material and Methods

A field experiment was conducted during the years 2010 and 2011 in Field experiments, Al-Hasa oasis, Kingdom of Saudi Arabia, in sandy loam soil to study the effect of tillage machine, water quality on vegetative growth, yield and water use efficiency WUE of Potato (*Solanumtuberosum L.*), Desiree Varity. The main factor of this study was two irrigation water sources (Fresh & Treated waste water) and the treatments of drip irrigation systems Drip surface (DIS), Drip subsurface 10 cm depth (DISS $_{10}$)and Drip subsurface 25 cm depth (DISS $_{25}$).

Some soil physical, chemical and water properties of the studied soil are carried out in tables 1, 2 and 3. The Moisture retention at field capacity and wilting point had been recorded. Soil in the investigated site was sandy loam in texture. Some soil chemical characteristics of the studied site were recorded in Table (2).

Irrigation Water Requirement (IWR) of potato during growing season for agricultural seasonal period were respectively 98.6 and 87.5 m^3/ha for Al-Hasa, KSA. **Doorenbos and Pruitt, (1977).** Experiment was planted on April, 9 during all the two years using seeding rate of 2000 kg ha^{-1} in 70 cm spaced rows. Fertilizers N, P and K were applied at 145, 80, 125 kg ha-1, respectively. To prevent any possible water deficit stress during the vegetative growth stage, irrigation was applied at 9, 13 days after sowing.

All plots were irrigated at 3days interval. Amount of irrigation water was measured at the entrance of each line of drip irrigation by a connected-flow-meter. Irrigation operation was stopped two weeks before harvested the potato yield. Net fertilizers were added by rates of 60: 35 : 45 % for N : P2O5 : K2O, so the plants had been received 87, respectively, according to the recommended amounts by the ministry of agriculture in KSA. Leaf area was calculated by digital plan meter in cm^2. Whereas LAI (Leaf area index) was calculated by dividing the total leaf area with the corresponding land area.

The data were subjected to analysis of variance (ANOVA) using Genstat. The significant differences between treatments were determined using least significant difference.

Table (1): Soil physical properties of the experimental site

Soil sample Depth (cm)	Particle size distribution (%)				Texture class	* FC	* WP	* AW	BD (g/cm^3)	HC (cm/h)
	Coarse sand	Fine sand	Silt	Clay		(V/V %)				
0-15	3.7	54.5	25.2	16.6	**SL**	0.22	0.11	0.11	1.45	1.11
15-30	3.8	55.8	24.6	15.8	**SL**	0.22	0.11	0.11	1.43	1.28
30-45	4.6	53.7	26.0	15.7	**SL**	0.22	0.11	0.11	1.43	1.28
45-60	4.6	55.9	25.5	14.0	**SL**	0.21	0.10	0.11	1.42	1.53

(*) Determined as percentage in (V/V %) cm^3 Water/ cm^3 Soil, (SL): Sandy loam, Soil; HC: Hydraulic conductivity; and BD: Bulk density.

Table (2): Chemical analysis of the soil

Soil sample depths (cm)	Cations (Meq/l)				Anions(Meq/l)				pH	E.C (dS/m)
	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	Cl^{-}	SO_4^{--}		
0-15	6.43	4.89	185.0	18.84	0	5.64	9.65	58.7	8.10	1.97
15-30	11.53	6.49	237.1	25.01	0	5.21	10.53	62.6	8.13	2.98
30-45	12.15	7.97	279.1	26.63	0	3.68	11.48	64.0	8.11	3.61
45-60	12.56	4.17	307.1	32.28	0	3.62	11.60	66.9	8.03	3.76

Table (3): Chemical analysis of irrigation water

Cations(Meq/l)				Anions(Meq/l)				pH	E.C (dS/m)
Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$CO_3^{=}$	Hco_3^{-}	Cl^{-}	$So_4^{=}$		
0.7	1.72	128	13	0.0	3.4	1.8	67	7.48	2.0

LAI = total leaf area / unit land area

Result and Discussion

Table (4) and Fig. (1) Shows the effect of Fresh water (FW), treated wastewater (TWW) and different drip irrigation systems: surface drip irrigation (DIS), subsurface drip irrigation by 10 cm depth (DISS10) and subsurface drip irrigation by 25 cm depth(DISS25) on number of plants per square meter, number of branches and plant length.

Number of plants per square meterin season 2010 as shown Table (4) and Fig. (1) under fresh water was the highest value (28.7) by using DISS25, followed by DISS10 value was (27.5). The lowest value (26.2) was achieved underDIS. Whereasunder treated wastewater was the highest value (29.0) by using DISS25, followed by (DISS10) value was (27.9). The lowest value (27.0) was achieved under (DIS).There were significant differences at the 5% level in number of plants per square meter between irrigation systems.

In season 2011 as showsboth Table (4) and Fig. (1) under fresh water was the highest value (29.4) by using DISS25, followed by (DISS10) value was (28.3). The lowest value (28.1) was achieved under (DIS). Whereasunder treated wastewater was the highest value (29.7) by using DISS25, followed by (DISS10) value was (28.8). The lowest value (28.3) was achieved under (DIS). There were significant differences at the 5% level in number of plants per square meter between any two irrigation systems. The increases in number of plants per square meter under fresh water in season 2011 were 3.5, 3.2 and 5.3 %. Whereas under treated wastewater were 2.7, 3.6 and 4.0 % in comparison with season 2010 under DIS, DISS10, and DISS25, respectively.The mean of branches number under fresh water as shows in Table (4) and Fig. (2) were 6.0, 5.9, and 5.6 (season 2010) and 6.1, 5.9 and 5.7 (season 2011).While under treated wastewater were 6.3, 6.1; 6.0 (season 2010) and 6.5, 6.2, 6.0 (season 2011)under DISS25, DISS10, and DIS, respectively.In both seasons the difference branch number between any two-irrigation systems was significant at the 5% level. The increases in branches number under fresh water in season 2011 were

2.9, 2.8 and 2.7 %. Whereas under treated wastewater were 2.6, 2.6 and 7.1 % in comparison with season 2010 under DIS, $DISS_{15}$, and $DISS_{30}$, respectively.

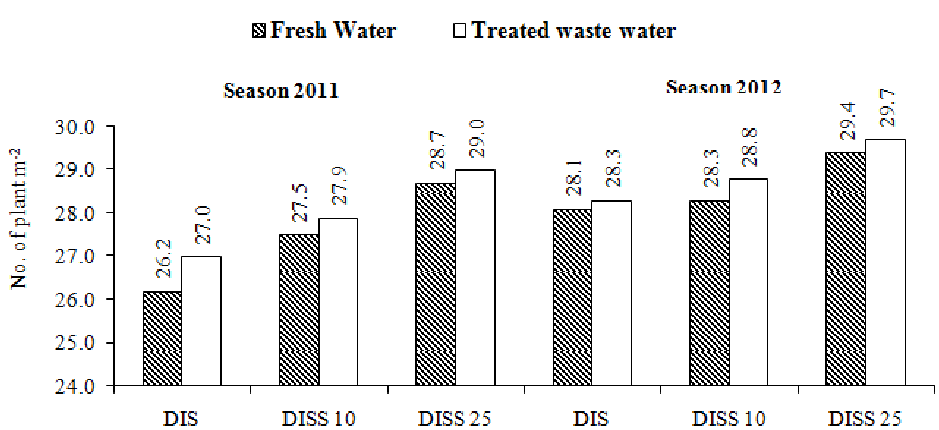
Table (4): Effect of water quality, drip surface and subsurface on vegetative growth of potato through two successful growing seasons 2010 and 2011.

Season 2010							
Water quality	**Fresh water**			**Treated wastewater**			**Mean**
Irrigation system	**DIS**	**DISS10**	**DISS25**	**DIS**	**DISS10**	**DISS25**	
Number of plants.m^{-2}	26.2	27.5	28.7	27	27.9	29	**27.7**
Number of branches	5.6	5.9	6	6	6.1	6.3	**6**
Plant length (cm)	51	51.6	52	52	52.1	52.3	**51.8**

Season 2011							
Water quality	**Fresh water**			**Treated wastewater**			**Mean**
Irrigation system	**DIS**	**DISS10**	**DISS25**	**DIS**	**DISS10**	**DISS25**	
Number of plants.m^{-2}	28.1	28.3	29.4	28.3	28.8	29.7	**28.8**
Number of branches	5.7	5.9	6.1	6	6.2	6.5	**6.1**
Plant length (cm)	50.8	51.1	52.7	52.1	52.5	53.1	**52.1**

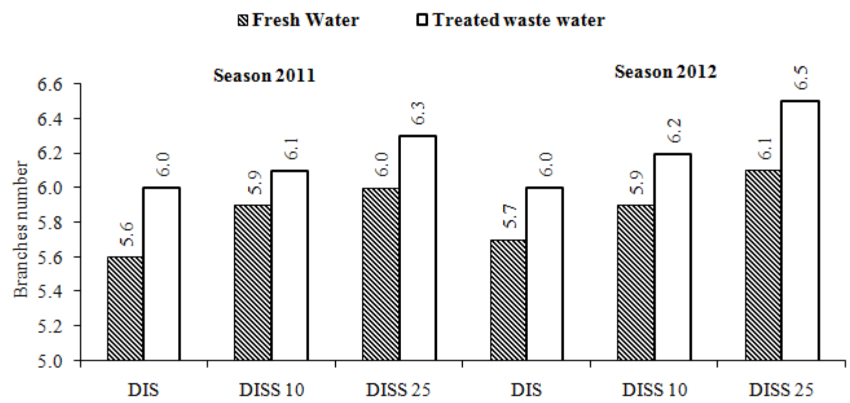
Statistical analysis	**Number of plants/m^2**	**Number of branches**	**Plant length (cm)**
LSD 0.05	**3.6**	**2.4**	**5.7**
Interactions	**3.5**	**2.3**	**5.8**

DIS: Surface Drip, DISS10: subsurface drip under soil depth 10cm, and DISS25: subsurface drip under soil depth 25cm



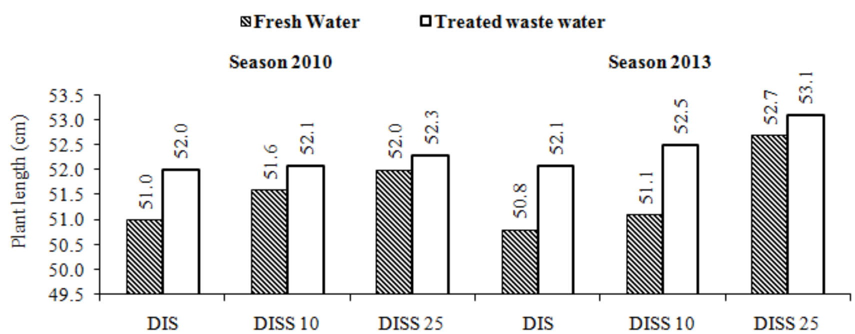
DIS: Surface Drip, $DISS_{10}$: subsurface drip under soil depth 10cm, and $DISS_{25}$: subsurface drip under soil depth 25cm

Fig. (1) Effect of water quality, drip surface and subsurface on number of plants per square meter of potato.



DIS: Surface Drip, $DISS_{10}$: subsurface drip under soil depth 10cm, and $DISS_{25}$: subsurface drip under soil depth 25cm.

Fig. (2) Effect of water quality, drip surface and subsurface on branches number of potato.



DIS: Surface Drip, $DISS_{10}$: subsurface drip under soil depth 10cm, and $DISS_{25}$: subsurface drip under soil depth 25cm

Fig. (3) Effect of water quality, drip surface and subsurface on plant length of potato.

Plant length under fresh water in cm as show Table (4) and Fig. (3) were 52.0, 51.6; 51.0 and 52.7, 51.1; 50.8. Whereas under treated wastewater as show Table (4) and Fig. (3) values were 52.3, 52.1; 52.0 and 53.1, 52.5; 52.1underDISS25, DISS10, and DIS, in bothseasons (2010) and (2011) seasons, respectively. The increase in mean of plant length (cm) were 0.42 % under when the 2011 season was compared by 2010. The difference in plant length factors and treatments under study were significant at the 5 % level. The data of potato growth supported by **Selim et al, (2009).**

The potato yield in season 2010 as shows by both Table (5) and Fig. (4) by using fresh water were the highest values withDISS25 (10946.1kg/ha), followed by DISS10 (9513.9kg/ha), while the lowest value of potato yield was (8388.6 kg/ha) under DIS. Whereas potato yield in season 2011 as shows by Table (5) also with DISS25 were the highest values (11048.4kg/ha), followed by withDISS10 value was (9718.5 kg/ha) and the lowest value of potato yield was (8695.5 kg/ha) withDIS. On the other hand the production yield of potato in season 2010 under treated wastewater were the highest values by using DISS25(11089.4kg/ha), followed by DISS10 (9778.5 kg/ha), while the lowest value of potato yield was (8797.8kg/ha) withDIS. Whereas potato yield in season 2011 as shows both Table (5) and Fig. (4),under DISS25 were the highest values (11150.7kg/ha), followed by the DISS10 value was (10434.6kg/ha) while the lowest value of potato yield was (9002.4 kg/ha) under DIS.

Table (5): Effect of water quality, drip surface and subsurface on yield and WUE of potato through two successful growing seasons 2010 and 2011.

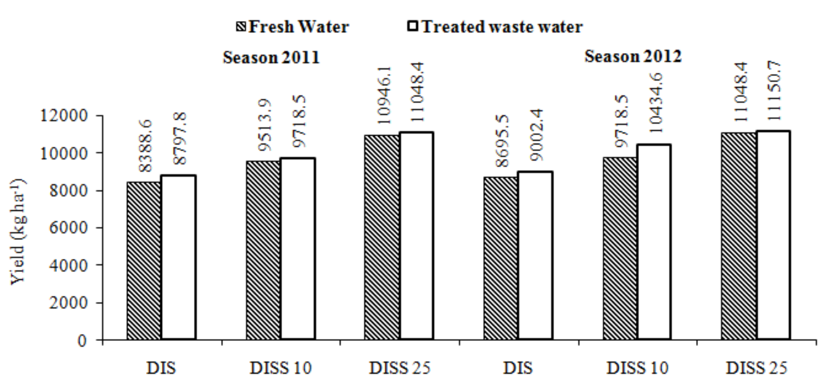
Season	2010						Mean
Water quality	Fresh water			Treated wastewater			
Irrigation system	DIS	DISS10	DISS25	DIS	DISS10	DISS25	
Water amount (m^3ha^{-1})	98.6						
Yield (kg ha^{-1})	8388.6	9513.9	10946.1	8797.8	9778.5	11089.4	**9735.6**
WUE ($kg.m^{-3}$)	85.1	96.5	111	89.2	98.6	112.1	**98.7**

Season	2011						Mean
Water quality	Fresh water			Treated wastewater			
Irrigation system	DIS	DISS10	DISS25	DIS	DISS10	DISS25	
Water amount (m^3ha^{-1})	87.5						
Yield (kg ha^{-1})	8695.5	9718.5	11048.4	9002.4	10434.6	11150.7	**10008.4**
WUE ($kg.m^{-3}$)	99.4	111.1	126.3	102.9	119.3	127.4	**114.4**

Statistical analysis	Yield (kg ha^{-1})	WUE ($kg.m^{-3}$)
LSD 0.05	120.5	8.6
Interactions	122.3	7.6

WUE: water use efficiency, DIS: Surface Drip, DISS10: subsurface drip under soil depth 10cm, and DISS25: subsurface drip under soil depth 25cm.

The differences in yield between factors and any two-irrigation systems were significant at the 5 % level in the two seasons. The data agreed well with those of **Simone et al., (2002). Selim et al, (2009)** found that Subsurface drip irrigation system was found to be more efficient than surface drip irrigation system on improving tubers yield quantity, qualityparameters and nutrients concentration content, in addition to soil fertility after harvesting.The data show that increase in season 2011 relative to season 2010 for potato yield was maximum under fresh water and DISS25(3.5%), followed by DISS10 (2.2%), while the minimum percentage of increase in potato yield (0.9%) when using DIS. On the other hand under treated wastewater values of increase percentage were 6.9,2.3 and 0.9% under DISS25, DISS10 and DIS, respectively.



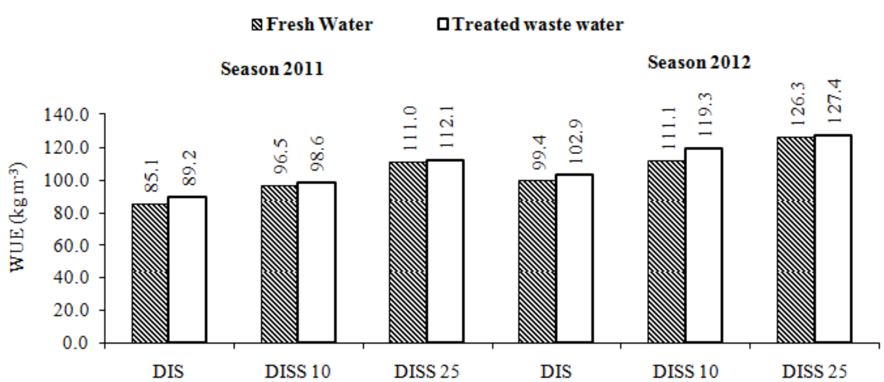
DIS: Surface Drip, $DISS_{10}$: subsurface drip under soil depth 10cm, and $DISS_{25}$: subsurface drip under soil depth 25cm.

Fig. (4) Effect of water quality, drip surface and subsurface on potato yield.

Concerning to water use efficiency (WUE), Table (5) and Fig. (5) shows that the data of season 2010,DISS25 is considerably the highest in values of both Fresh and Treated waste water (111.0 and 112.1kg/m^3, respectively), followed by the (DISS10) values (96.5 and 98.6kg/m^3), while the lowest values of both Fresh and Treated waste water were (85.1and 89.2kg/m^3, respectively) by using (DIS).

In season 2011, Table (5) and Fig.(5), indicated that (DISS25) has the highest values of both Fresh and wastewater (126.3 and 127.4kg/m^3 respectively). Under (DISS10) those values were (111.1 and 119.3kg/m^3, respectively), while the lowest values of Fresh and Treated wastewater were (99.4and 102.9 kg/m^3, respectively) under (DIS).

The increase in WUE in season 2011 relative to season 2010 in both Fresh and Treated wastewater were (2.9, 1.8; 0.8 % and 2.3, 1.3; 0.8 %), respectively. **(Hanson and May, 2004)** states that the term 'micro-irrigation' refers to drip, trickle, spray, micro jets or mini-sprinkler systems designed to use available watermore effectively that slowly and frequently provides water directly to the plant root zone. Moreover, drip irrigation provides anefficient method of fertilizer delivery virtually free of culturalconstraints that characterize other production systems. Subsurfacedrip irrigation is considered to be the most modern irrigationsystem with efficient water delivery that can contribute immenselyon improving crop water use efficiency and conserving water.Most agricultural irrigation scientists arein agreement that fertilization through subsurface drip irrigationsystem could be the ideal fertigation systems. **Rajkumari et al.(2006)** hypothesized that injecting N fertilizer into subsurfaceirrigation systems should in theory be as efficient as the irrigationdelivery system itself is.Achieving maximum fertigation efficiency requires knowledgeof crop nutrient requirements, soil nutrient supply, fertilizerinjection technology, irrigation scheduling, crop and soil monitoringtechniques. If properly managed, fertigation through dripirrigation lines can reduce overall fertilizer application rates andminimize adverse environmental impact of vegetable production**(Hochmuth, 1992).**



DIS: Surface Drip, $DISS_{10}$: subsurface drip under soil depth 10cm, and $DISS_{25}$: subsurface drip under soil depth 25cm

Fig. (4) Effect of water quality, drip surface and subsurface on WUE.

Conclusion

It could be concluded that for vegetative growth, yield and WUE:

1. The increases in number of plants per square meter under fresh water at 2^{nd} season 2011 were 3.5, 3.2 and 5.3 %. Whereas under treated wastewater were 2.7, 3.6 and 4.0 % in comparison with season 2011 under DIS, DISS10, and DISS25, respectively.
2. The increases in branches number under fresh water at season 2011 were 2.9, 2.8 and 2.7 %. Whereas under treated wastewater were 2.6, 2.6 and 7.1 % in comparison with season 2011 under DIS, DISS10, and DISS25, respectively.

3. The increase in mean of plant length (cm) were 0.4 % under when the 2nd season was compared with the 1st one. The difference in plant length factors and treatments under study were significant at the 5 % level o at the 1st and 2nd season.
4. The data shows that increase in season 2011 relative to season 2010 for potato yield was maximum under fresh water and DISS25(3.5%), followed by DISS10 (2.2%), while the minimum percentage of increase in potato yield (0.9%) when using DIS. On the other hand under treated wastewater values of increase percentage were 6.9, 2.3 and 0.9% under DISS25, DISS10 and DIS, respectively.
5. The increase in WUE at the 2nd season relative to 1st season one in both Fresh and Treated wastewater were (2.9, 1.8; 0.8 % and 2.3, 1.3; 0.8 %)under DIS, DISS10, and DISS25, respectively.
6. From mentioned above, the best of potato production where potato vegetative growth parameters, yield, and WUE, so it can be recommend to using subsurface drip irrigation depth (25 cm) with treated wastewater under current experiment condition.

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