EFFICENECY OF IRRIGATION SYSTEMS UNDER WATER DEFICIT CONDITIONS IN SALINE CALCAREOUS SOILS

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ABSTRACT

A field experiment was carried out during winter season 2005-2006 at Ras Sudr Experimental Station of the Desert Research Center, to evaluate the performance of five irrigation systems: continuous flow furrow (CF); surge flow furrow (SF); surface drip (D0); and subsurface drip (SDI) at two depths of 15 and 30 cm (D15) and (D30), respectively, using two different levels of irrigation water application (100 and 70% of crop water requirements) designated as (T) and (0.7T), respectively, to irrigate fodder beet crop in calcareous loamy sand soil. The source of irrigation water was ground well and the average water salinity was 4.36 dS/m. The experiment carried out in split plots design. The obtained results indicated that the maximum average values of AE% were 85.8, 88.1, 93.5, 97.4, and 97.1% obtained by applying 0.7T treatment under CF, SF, D0, D15, and D30 treatments, respectively. The maximum average values of DU were 0.52, 0.62, 0.88, 0.95, and 0.94 obtained by the same treatments, respectively. Maximum average fresh yield (roots and tops) was 38.34 ton/fed. obtained by (D15xT) treatment, the increment reached to 6.9% compared to D0 with non-significant differences compared with D30. Meanwhile, surge flow furrow SF treatment recorded 31.62 ton/fed. as maximum average yield companied with applying T treatment, with increment of 22.7% compared with CF. The average values of irrigation water use efficiency (IWUE), obtained by D15 or D30 treatments, were superior to D0 treatment under the experiment conditions. Meanwhile, the highest average value of IWUE was 16.85 kg/m^3 obtained by (D15x0.7T) treatment, and the lowest average value 10.86 kg/m^3 resulted by (D0xT) treatment. In the same time, the average value 8.75 kg/m^3 obtained by SF resulted from applying (SFx0.7T) treatment, with increment reaching to 48.6% compared with CF treatment.

Keywords: drip, subsurface drip, furrow irrigation, surge flow, performance parameters, deficit irrigation, fodder beet, irrigation water use efficiency.

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INTRODUCTION

With increasing demands on limited water resources and the need to minimize adverse environmental consequences of irrigation, drip irrigation technology will undoubtedly play an important role in the future of the Egyptian agriculture. It provides many unique agronomic, water and energy conservation benefits that address many of the challenges facing irrigated agriculture. Application of uniform and sufficient water to seed for good crop establishment is one of the most challenge issues of subsurface drip irrigation (SDI), (Camp, 1998). Quantification allows the users to determine and control the dripper discharge, amount and timings of application of irrigation water, so that the crop water requirements are met in a planned and effective manner, (Thorburn *et al.,* 2003). Various studies have rated most of the SDI systems as excellent based on their performance (Ayars *et al.*, 1999). Water infiltration in the SDI takes place in the region directly around the drippers, which is small compared with the total soil volume of irrigated field. Desired wetting patterns of soil can be obtained by selecting the appropriate dripper discharge and spacing (Lubana and Narda, 2001). Water distribution in the soil around a buried dripper mainly depends on soil texture, dripper discharge and root water uptake (Cote *et al.*, 2003).

High level of salts in the irrigation water (up to 4.8 dS/m), irrigation purely with irrigation water of high salinity can cause reduction in crop yield, Dorrenbos and Pruitt (1977). Surge flow irrigation as a surface irrigation technique applied to furrows intermittently during a single irrigation set. However, Awady *et al.* (1988) concluded that the intermittent application of water increases water distribution efficiency and yield of water use efficiency in clay soil with 50-m long furrows. Yield water use efficiency for surge irrigation was correlated to numerous factors as cycle ratio, total number of pulses per irrigation, flow rate, depth of irrigated soil, field geometrical, permeability of soil and slope. The cycle ratio affects yield of water use efficiency among other factors. The water required was 23% less than continuous irrigation.

The present experiment conducted mainly to study the effect of using saline water application levels on both the performance of irrigation systems and crop yield in calcareous loamy sand soil conditions. The specific objectives of this study were: 1) to evaluate the performance parameters of drip and furrow irrigation systems under different practices, and 2) to find out the effects of application level of saline irrigation water by the mentioned irrigation systems on total fresh yield of fodder beet crop, water reserves and IWUE.

MATERIALS AND METHODS

1. Location and soil properties of the experiment site:

A field experiment was carried out in the Agricultural Experimental Station of Desert Research Center (*DRC*) at Ras-Sudr, South-Sainai Governorate (29^o 35` 31`` N-$32^o$ 41` 30`` E) during winter season 2005/2006. Some relevant physical and chemical properties of the soil experimental site were analyzed according to the methods described by Klute (1986) and shows in Tables (1 and 2). The soil is calcareous loamy sand in texture, $CaCO_3$ content is very high (42.4%), and the organic matter content is 0.15%. The soil is saline mildly alkali, no-water table found. The main source of irrigation water is ground well, and some chemical properties of the irrigation water are represents in Table (3).

Table 1: Some physical properties of the soil experimental site.

Soil depth (cm)	Particle size distribution (%)				*$K_{Sat.}$ (cm/h)	Db (g/cm3)	Field Capacity (V%)	W.P (V %)	A. W (V %)
	Coarse Sand	Fine Sand	Silt	Clay					
00-30	53.21	27.88	9.06	9.85	3.77	1.56	19.9	10.07	9.83
30-60	60.12	24.94	7.59	7.35	4.81	1.57	18.54	9.40	9.14
60-90	47.47	34.39	10.23	7.91	3.83	1.59	17.16	11.00	6.16
90-120	51.02	30.55	10.11	8.32	3.30	1.60	17.83	10.90	6.93

* $k_{sat.}$= Saturated hydraulic conductivity, D_b= Bulk density, W.P= Wilting point at 15 bar, A.W= Available water.

Table 2: Some chemical properties of the soil experimental site.

Soil depth (cm)	pH	EC (dS/m)	Soluble Cations (meq/l)				Soluble Anions (meq/l)			
			Ca^{++}	Mg^{++}	Na^+	K^+	$CO_3^=$	HCO_3^-	Cl^-	$SO_4^=$
00-30	7.48	6.14	14.76	12.75	34.67	1.61	-	2.49	31.79	29.51
30-60	7.22	7.28	16.85	21.48	36.22	1.09	-	2.30	41.49	31.85
60-90	7.15	7.44	17.04	24.62	34.08	1.55	-	2.25	38.52	36.52
90-120	7.16	7.50	18.05	24.86	34.17	0.84	-	2.53	40.63	34.76

Table 3: Some chemical properties of the irrigation water.

pH	SAR	EC (dS/m)	Soluble Cations (meq/l)				Soluble Anions (meq/l)			
			Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$CO_3^{=}$	HCO_3^{-}	Cl^{-}	$SO_4^{=}$
7.62	11.98	4.36	7.68	5.09	30.27	0.56	-	2.1	29.19	12.31

2. Irrigation systems installation and experimental treatments:

The experiment was carried out with split plot design with three replicates at random procedure. The main plots represent five irrigation systems: continuous flow furrow (CF); surge flow furrow (SF); surface drip (D0); and subsurface drip (SDI) at two laterals depths, 15 and 30-cm (D15 and D30), respectively. Each main plot of drip system was 13.5 $*$ 33 m, whereas in surface furrow each main plot was 13.5 $*$ 76 m and divided into two equal subplots representing the two levels of irrigation water application at 100 and 70% of crop water requirements (denoted as T and 0.7 T, respectively). Each subplot was 6.75 m wide including 9 ridges. Fodder beet (*Beta vulgaris L.*) cv. vulgaris sown on Sept. 19$^{th..}$, 2005. Plant density was 5 plants/m^2 in average. Farmyard manure compost applied uniformly at the rate of 12 m^3/fed. during soil preparation, and followed by recommended doses of potassium (as potassium sulphate); phosphorus (as calcium super phosphate) and nitrogen (as ammonium nitrate) fertilizers at the rate of 96; 62; and 100 kg/fed., respectively, and all plots received the same agricultural practices along growth season.

Each subplot had one valve, pressure gauge and flow-meter to control the applied irrigation water volume. Control head facilities in drip systems included double disk filters, fertilizer injector, main flow-meter and other safety tools. Polyethylene (PE) drip lines 16 mm indiameter were installed manually at depths of 0.0, 15.0, and 30.0 cm in the middle of ridges. Care was taken to lay the drip lines straight on the center of the ridges. Three inline GR drippers per 1.0 m length, with 11.85 lph/m flow rate operated at 1.05 bar.

In furrow irrigation, the SF cycle time was 18 min. (6 min ON and 12 min OFF), with 0.33 cycle ratio. Both the surge and continuous irrigation system managed with inflow rate adjusted to 1.05 and 0.75 lps/gate-furrow for considered T and 0.7T treatments, respectively, and checked by volumetric methods during several irrigation events according to Walker

(1989). Soil surface slope was 0.2%. Irrigation runoff was negligible, where the furrows had closed-ends. Thus, the net amount of irrigation water was the amount of water added to the field during each irrigation event coincided with the crop's growth stage according to Dorrenbos and Pruitt (1977). Soil moisture content estimated volumetrically, were carried out according to the method described by Walker (1989), started from ridge surface till 1.2 m depth with increment of 0.15 m to follow the soil moisture at $1^{st.}$, $2^{nd.}$, $3^{rd.}$, $4^{th.}$ and $5^{th.}$ growth stages of fodder beet crop, and directly before and 24 h after 1^{st}, 9^{th}, 15^{th}, $22^{nd.}$ and $28^{th.}$ irrigation events with drip irrigation treatments and at 1^{st}, 5^{th}, $8^{th.}$, $12^{th.}$, and $15^{th.}$ with furrow treatments. Soil samples were collected using soil auger sampler at four places on the ridge distance at the first, second, third and fourth quarter.

3. Estimation of water uniformity by irrigation systems:

In this study tests for uniformity of water distribution by drip system were carried out according to the method described by Kruse (1978) and Bralts *et al.* (1981) in terms of coefficient of variation (CV), statistical uniformity (SU), distribution uniformity (DU), and application efficiency (AE%). The AE% calculated for the 60 cm soil depth According to James (1988) as follows:

$$AE = \frac{Ws}{W_f} \times 100$$

Where:

AE = water application efficiency, %;
W_s = amount of water stored in the root zone, m^3; and
W_f = amount of water added to each plot, m^3

Distribution uniformity (DU) is the ratio of the average of the lowest one-fourth of measurements of water infiltrated depths divided by the average depth of water infiltrated over actual field length. DU values calculated according to the method described by Burt *et al.*, (1997). Results of AE% and DU were statistically analyzed according to Snedecor and Cochran, (1982).

4. Estimation of water requirements and irrigation schedule:

Irrigation water was applied when the available soil moisture content depleted to nearly 50% in the upper 60 cm of soil profile in order to raise the soil moisture content to field capacity. Weather data collected from an automatic weather station located in Ras-Sudr Experimental Station. Reference crop evapotranspiration (ET_o) was calculated using Penman–Monteith's formula and the methodologies formulated by Dorrenbos and Pruitt (1977) and Allen *et al.* (1998) to calculating the crop evapotranspiration (ET_c), leaching requirements and determining the irrigation schedule. The amount of irrigation water calculated according to the equation given by James (1988):

$$ET_C = I + P \pm \Delta S - R - D$$

Where: ET_c = crop evapotranspiration (mm);
I = irrigation amount (mm);
P = precipitation (mm);
ΔS = change of soil water storage (mm);
R = surface runoff (mm); and
D = deep percolation below crop root zone (mm).

Since the precipitation in the growing season was small, the deep percolation and surface runoff could be ignored under the experiment conditions. Therefore, the irrigation amount estimated using the field balance equation as follows:

$$I = ET_C \pm \Delta S$$

5. Fodder beet yield:

Harvesting of fodder beet started manually after 155 day from sowing. Yield samples (fresh roots and tops) from each treatment and its replications were recorded. Standard analysis of variance (ANOVA) used to evaluate the effects of the treatments on the yield and to determine the significance of the main treatments and its interaction with sub treatments. Least significance differences (LSD) test used for comparing at $P < 0.05$ according to Snedecor and Cochran, (1982).

6. Irrigation water use efficiency (IWUE):

IWUE was calculated according to James (1988) as follows:

$$IWUE = \frac{Y}{W_a}$$

Where: IWUE = irrigation water use efficiency, kg/m^3,
Y = total fresh yield, kg/fed., and
W_a = total applied irrigation water, m^3/fed.

Data of IWUE were statistically analyzed according to Snedecor and Cochran, (1982).

RESULTS AND DISCUSSIONS

1. Performance of the irrigation systems:

Evaluation of the performance parameters of the installed drip irrigation system at the beginning of the experiment indicated that the coefficient of variation (CV) of flow rates was 0.052, which means a good performance of the system. Decroix and Malaval (1985) had concluded that a CV between 0.05 and 0.066 indicates a good performance of the drip system. Average value of statistical uniformity (SU) was 94.77%, and according to Kruse (1978), SU greater than 90.0% implies an excellent functioning of the drip system. Performance parameters for considered irrigations under treatments are shown in Figs. (1a and b). Data represents that the average estimated values of AE% and DU for considered irrigation systems were vary under water application level treatments.

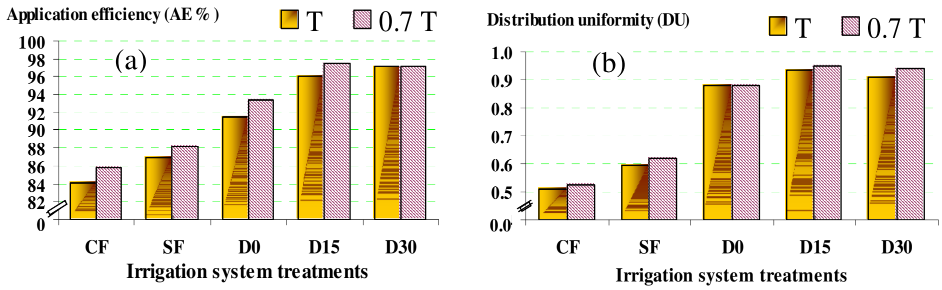

Fig. 1: Average estimated values of AE% (a) and DU (b) for considered irrigation systems under water application level treatments.

Average obtained values of AE% under CF, in Fig. (1a), indicated that about 15.9 – 14.2% of the water applied at T and 0.7T treatments, respectively, were wasted or not available for the crop among the treatments. These losses were 13.0 – 11.9% under SF by T and 0.7T treatments, respectively. Whereas; by drip irrigation, AE% was not significantly affected by the position of drip line at treatments D15 or D30 ($P < 0.05$).

The obtained average DU values in Fig. (1 b) demonstrate clearly that DU affected significantly by the irrigation system under water applied levels. The maximum average values of DU were 0.95 and 0.94 obtained by D15 and D30, respectively, using 0.7T treatment, with non-significant differences with T treatment ($P < 0.05$), the increments ranged from 8.2 to 6.3% compared with D0, respectively. On the other side, SF treatment recorded 0.62 and 0.6 by 0.7T and T treatment, respectively, with significant differences compared with CF irrigation. These results were in accordance with that obtained by Kanber *et al.* (2001), they reported that the higher DU under SF could refer to the surface seal and consolidation of the top layer of soil due to wet/dry cycles, that caused lowering the surface hydraulic roughness of the wet advance than that in the surface hydraulic roughness of the dry advance. Yonts *et al.* (1996) who reported that, surge irrigation was an effective method for decreasing the intake rate of soil and allowing water to advance rapidly.

2. Effect of irrigation system and water application level on fodder beet total fresh yield:

Maximum average total fresh yield of fodder beet was 38.33 ton/fed. obtained with D15xT treatment, Fig. (2). The increment reached to 6.9% compared with D0xT treatment with non-significant differences with D30xT treatment ($P < 0.05$). With D15x0.7T treatment, avg. total yield was 31.1 ton/fed., the increment about 3% compared with D0x0.7T treatment, with non-significant differences existed compared with D30x0.7T treatment. This could be attributes to the predominant role of gravity than the capillary forces in soil water movement, with decreasing of water loss by evaporation from soil surface, so shallow depth of drip line recommended in fodder beet crop to get higher yield under the same experiment conditions.

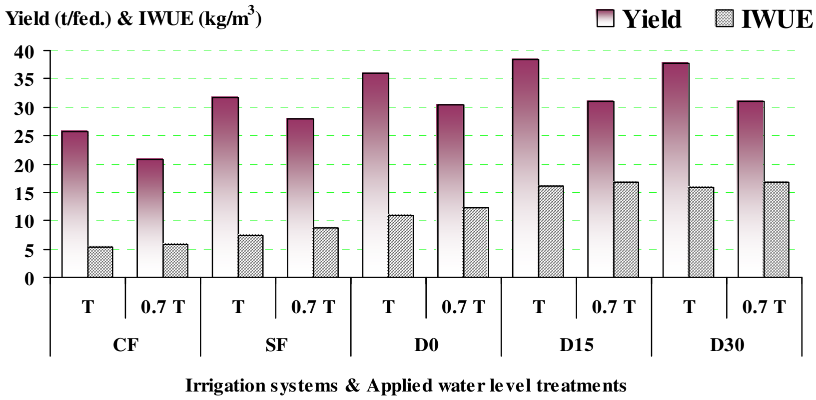

Fig. 2: Average total fresh yield of fodder beet (ton/fed.) and IWUE (kg/m^3) by different irrigation systems under water applied level treatments.

The results are accordance with that obtained by Amali *et al.* (1997) they found that the soil moisture variability in SDI was considerable with non-uniform soil water contents above the driplines; and variability in water contents below the driplines depth was similar to the surface irrigation systems. On the other hand, surge flow furrow recorded avg. yield of 31.62 ton/fed. by SFxT treatment, with significant increment of 22.7% compared with CFxT treatment. Meanwhile, using SFx0.7T treatment recorded 34.05% increase in total yield compared with CFx0.7T treatment. Lower yield in CF maybe attributed to irrigation water ponds at the furrow ends with each irrigation event. Too much water might have caused partially poor aeration of roots, and soil nutrients leaching, (Xiao *et al.*, 2004).

3. Irrigation water use efficiency (IWUE):

The average values of IWUE shown in Fig. (2). The highest average value 16.85 kg/m^3 recorded by D15x0.7Ttreatment, the increment reached 38.7% compared to D0x0.7T treatment, with non-significant difference existed compared with D30x0.7T treatment. Meanwhile, treatment D15xT resulted average value of 16.05 kg/m^3, the increment reached to 47.9% compared to D0xT treatment with non-significant difference existed compared with D30xT treatment. D0x0.7T treatment, obtained average value 12.22 kg/m^3, the increment reached to 11.9% compared to D0xT treatment. Generally, the average recorded values of IWUE with SDI were higher than these obtained by surface drip at any level of applied irrigation water. In case of water application level 0.7T treatment, the increments in avg. IWUE values were ranged from 4.9 to 11.9% among different dripline depths compared with T treatment, in the same time, it were 8.0 and 17.9% recorded by CF and SF treatments, respectively. The surge furrow irrigation, SFx0.7T treatment, obtained average value 8.75 kg/m^3, it was 48.6% higher than that obtained by CFx0.7T treatment. Meanwhile, treatment SFxT resulted average value of 7.42 kg/m^3, the increment reached to 36.0% compared to CFxT treatment. These results were in accordance with that obtained by Hiekal (2007), with better water distribution in the soil profile; consequently, less water lost by deep percolation along furrow length, especially for early season irrigations, where the high infiltration rates can result in low application efficiencies with the CF compared with SF. Moreover, the difference in yield is sufficient to interest the farmers to do the extra work involved in changing the traditional irrigation practices to rationalize their cultivated areas in order to save water and time of irrigation.

4. Amounts of applied irrigation water and savings:

The total amounts of applied irrigation water throughout the treatments are shown in Fig. (3). The differences in applied irrigation water between SDI and surface drip treatments may be attributed to superior SDI treatments of good distribution uniformity and less evaporation lost from the upper soil layer compared with surface drip treatments. On other side, SF saved irrigation water by 10.8% in average compared with CF treatment.

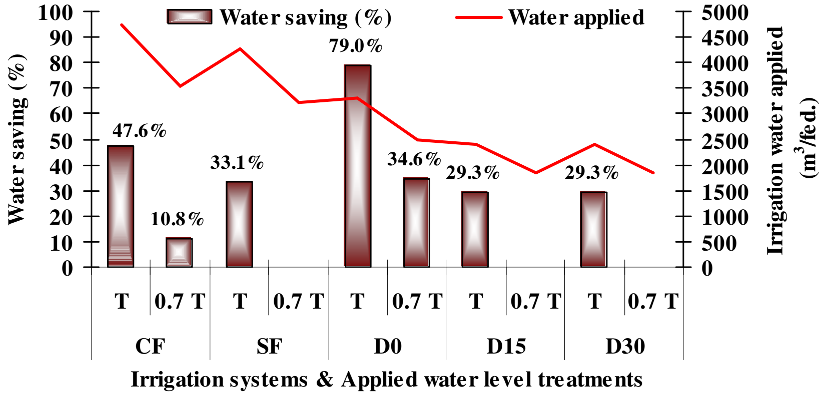

Fig. 3: Total irrigation water applied and water saving percent using 0.7T in both SF and SDI systems compared with other treatments.

Obtained results which demonstrated that using 70% of crop water requirements are capable for saving 79.0, 34.6 and 29.3 % of irrigation water by D15x0.7T treatment compared with D0xT, D0x0.7T and SDIxT treatments, respectively. In addition, surge flow by SFx0.7T treatment, up to 47.6, 33.1 and 10.8% saving in irrigation water compared with CFxT, CFx0.7T and SFxT treatments, respectively.

CONCLUSION

From obtained results, it could be concluded that the performance of the drip systems was good, with the values of SU was found 94.77%. Application efficiency (AE%) was significantly affected by the irrigation system, whereas; it was not significantly affected by the position of drip line at 15 or 30 cm in treatments D15 or D30, respectively. The highest average value of AE% was 97.44% obtained under D15 at 70% of water requirements, D15x0.7T treatment. Meanwhile, it was 88.12% by surge flow furrow, SFx0.7T treatment. Distribution uniformity (DU) was significantly affected by the irrigation system under any water-applied level. The maximum average value of DU was 0.95 obtained by D15x0.7T treatment. Meanwhile, the DU value was 0.62 by SFx0.7T treatment.

The buried depth of drip line was significantly affected the fodder beet fresh yield, and the maximum yield obtained by applying 2387.3 m^3/fed. of irrigation water under SDI treatments over either surface drip or furrow irrigation treatments. Maximum average total fresh yields were 38.33 and 31.62 ton/fed. recorded by 100% water applied level (T) under D15xT and SFxT treatments, respectively. Both SDI and SF treatments saved irrigation water compared with D0 and CF treatments at any applied water level. The highest avg. value 16.85 kg/m^3 of irrigation water use efficiency (IWUE) recorded by D15x0.7T treatment. Meanwhile, D15xT treatment recorded an avg. value of 16.05 kg/m^3. Surge flow furrow irrigation, SFx0.7T treatment, obtained avg. value of 8.75 kg/m^3.

It is recommended to achieve higher yields, under saline and scarce water resource in dry areas conditions that drip line should be buried at depth of 15 -30 cm and the deficit water level not greater than 25-30% in like sites in Wadi Sudr area conditions. If sufficient resource of irrigation water is available to fodder beet growers, higher avg. yield as 38.33 ton/fed. could be achieved by placing the drip line at 15.0 cm soil depth or using surge flow furrow irrigation to obtain avg. yield as 31.62 ton/fed. Otherwise, in the water deficit conditions, higher avg. yield as 31.09 ton/fed. could be achieved by placing the drip line at either15 or 30 cm soil depth or using surge flow furrow irrigation to obtain avg. yield like 28.01 ton/fed.

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الملخص العربى

كفاءة نظم الرى تحت ظروف العجز المائى فى الأراضى الجيرية الملحية

حسام الدين محمد هيكل*

أجريت تجربة حقلية خلال الموسم الشتوى 2006/2005م بمحطة بحوث راس سدر التابعة لمركز بحوث الصحراء، بهدف تقييم أداء خمسة نظم للرى هى رى الخطوط بأسلوب الاضافة المستمر لمياه الرى (CF)، والخطوط المطور بأسلوب الاضافة النبضى (SF)، التنقيط السطحى (D0)، والتنقيط تحت السطحى (SDI) على عمقين 15و30 سم من سطح التربة (D15) و(D30) على الترتيب. مع تطبيق مستويين لإضافة مياه الرى: 100و70% من الاحتياجات المائية للمحصول (T) و(0.7T)، على الترتيب، لزراعة بنجر العلف بأرض جيرية ملحية ذات قوام رملى طميي، ومصدر المياه بئر جوفى متوسط ملوحة مياهه 4.36 ديسيمنز/م.

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صممت التجربة بنظام القطع المنشقة. وقد تم تقييم أداء المعاملات المختلفة للرى من خلال مقاييس الأداء مثل معامل الاختلاف (CV)، والانتظامية الإحصائية (SU)، وكفاءة الإضافة (AE%)، وانتظامية التوزيع (DU)، كما قدرت كفاءة استخدام المياه فى رى المعاملات المختلفة (IWUE). وقد أشارت النتائج المتحصل عليها الى أن:

- أداء نظم الرى بالتنقيط كان جيدا خلال الموسم، وكانت متوسطات قيم (CV) و(SU) هى 0.052 و94.77%على الترتيب. كما بلغت أقصى متوسطات قيم كفاءة الإضافة لمياه الرى (AE%) 85.8، 88.1، 93.5، 97.4، 97.1% لكلا من (CF)، (SF)، (D0)، (D15)، (D30)، على الترتيب مع معاملة الاضافة لمياه الرى عند مستوى 70% من الاحتياجات المائية (0.7T). كما بلغت أقصى متوسطات قيم انتظام التوزيع الرطوبى (DU) 0.52، 0.62، 0.88، 0.95، 0.94، لنفس المعاملات على الترتيب.
- أعلى متوسط للمحصول الكلى الطازج (جذور وأوراق) 38.34 طن/ف لمعاملة إضافة مياه الرى 100% من الاحتياجات المائية (T) وكمية مياه مضافة 2387.3م^3/ف مع معاملة (D15) ، بمتوسط زيادة للمحصول6.9% عن معاملة الرى بالتنقيط السطحى (D0) وكمية مياه مضافة 3303.1م^3/ف ، وكان الفرق غير معنوياً مع التنقيط تحت السطحى (D30)، بينما كان أعلى متوسط للمحصول الطازج 31.62 طن/ف عند نفس معدل الاضافة لمياه الرى (T) وكمية مياه مضافة 4262.0م^3/ف باستخدام نظام الخطوط بالأسلوب النبضى (SF) بمتوسط زيادة 22.7% للمحصول عن معاملة الرى بالخطوط بأسلوب الاضافة المستمر (CF) وكمية مياه مضافة 4725.5م^3/ف.
- معاملات الرى تحت السطحى (D15,30x0.7T) وفرت فى مياه الرى بنسب 34.6، 79.0% بالمقارنة بمعاملات التنقيط السطحى (D0x0.7T) و (D0xT)، على الترتيب. بينما معاملات الرى بالخطوط بالأسلوب النبضى (SFx0.7T) وفرت فى مياه الرى بنسب 10.8، 33.1، 47.6% بالمقارنة بمعاملات (CFx0.7T)، (SFxT)، (CFxT)، على الترتيب.
- متوسطات قيم IWUE الناتجة من تطبيق معاملات SDI أعلى من مثيلتها الناتجة من تطبيق معاملات التنقيط السطحى عند أى من مستويات الإضافة لمياه الرى. معاملة (D15x0.7T) سجلت 16.85 كج/م^3 كأعلى متوسط لقيم IWUE، بينما لمعاملة (D0xT) كان أقل متوسط 10.86 كج/م^3 ، وفى نفس الوقت، باستخدام نظام الخطوط بالأسلوب النبضى (SFx0.7T) سجلت 8.75 كج/ م^3 بزيادة قدرها 48.6% عن معاملة (CFx0.7T) تحت ظروف الدراسة.