Effect of Land Leveling and Water Applied Methods on Yield and Irrigation Water Use Efficiency of Maize (*Zea mays* L.) Grown under Clay Soil Conditions

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Abstract: Field experiments were conducted at the farm of El-Karada Agricultural Research Station, Kafer El-Sheikh Governorate, Egypt, during two successive summer seasons 2012 and 2013. The experiment was arranged in strip-plot design with four replicates. The main-plot represented land leveling methods [slope of zero% = 0 cm/ 100 m length (L_1) & 10 cm/100m length (L_2)]. While, the sup-plot treatments represented water applied methods, e.g. [Continuous flow irrigation (I_1) - Alternative furrows irrigation (I_2) and surge irrigation with different cycle ratios (I_3)]. Surge Irrigation cycle ratio was as the follows: (I_{3a}) ratio with 50% {9 min on and 9 min off}, (I_{3b}) ratio with 66% {{9 min on and 6 min off}} and (I_{3c}) ratio with75% {9 min on and 3 min off}. Results indicated that under zero % slope method received more amount of irrigation water, irrigation water use efficiency and water distribution efficiency % was opposite. Also, data revealed that, alternative furrows irrigation gave the highest values of irrigation water use efficiency (IWUE), while water distribution efficiency was opposite. On the other side, the surge cycle ratio received more amounts of water and increase water consumptive use, water distribution efficiency, while, the lowest values of grain yield. Whereas, the best treatment with surge cycle ratio at 50% and at 75% was opposite. It can be summarized that alternative irrigation method with slope 0.01% saved and decreased amount of water irrigation applied 35% and 30% than continuous flow irrigation and surge cycle rations. Alternative irrigation method with slope 0.01% produced the highest value of irrigation water use efficiency.

Key words: Alternative furrows irrigation · Land leveling, maize crop · Surge irrigation

INTRODUCTION

Many ways of conserving agricultural water have been investigated. Stewart *et al.* [1], Hodges *et al.* [2], Graterol *et al.* [3] and Stone and Nofziger [4] have used wide-spaced furrow irrigation or skipped crop rows as a means to improve water use efficiency (WUE). They fixed some furrows for irrigation, while adjacent furrows were not irrigated for the whole season. In general, these techniques are a trade-off: a lower yield for a higher WUE. Water was saved mainly by reduced evaporation from the soil surface. Ideally, WUE should be improved by reduced leaf transpiration as stomata control leaf gas exchange and transpiration water loss. Recent investigations have shown that stomata may directly respond to the availability of water in the soil by reducing their opening [5, 6]. The advantage of this type of regulation is that

plants may delay the onset of serious leaf water deficit and enhance their chance of survival in times of unpredictable rainfall: the optimization of water use for CO_2 uptake and survival [7, 8]. More recent evidence has shown that this feed-forward stomata regulation works through a chemical signal, i.e. increased concentration of abscisic acid (ABA), in the xylem flow from roots to shoots [5,9,10,11]. Part of the root system in drying soil can produce large amount of ABA while the rest of the root system in wet soil may function normally to keep the plant hydrated [12,13]. The result is that plants may have a reduced stomata opening with the absence of visible leaf water deficit.

To take advantage of this type of plant response, Kang *et al.* [14] suggested that irrigation might be designed so that part of the root system is exposed to drying soil while the rest is in wet soil. They hoped that

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such a design could lead to reduced stomata opening without leaf water deficit. Kang *et al.* [15] conducted an experiment with pot-grown maize plants where the plant root system was divided into two or three containers which were watered alternately. Compared to conventional watering or watering fixed parts of the root system, alternate irrigation reduced water consumption by 35% with a total biomass reduction of only 6±11%. We adopted this approach in a field experiment on irrigated maize plants for 2 consecutive years. The hypothesis was that irrigating alternate furrows, i.e. partial wetting of the root system alternatively, might save water. WUE might be increased with a small reduction in grain yield although the total biomass might be reduced with less irrigation. This approach was also encouraged by the results of more recent investigation on grapevines [16, 17]. They adopted a partial root-zone drying approach and found that WUE was nearly doubled with better quality grapes and no yield reduction. A primary aim for good irrigation management is to minimize deep percolation of water (infiltration exceeding the irrigation requirements). Deep percolation losses depend directly on irrigation systems performance, which in turn, depends mainly on how evenly water infiltrates a cross the field. Eid *et al*. [18] showed that surge flow system seemed to be better than continuous irrigation, because it caused less run off, less deep percolation, less opportunity for loading of nutrients chemical minerals in the ground. Matter [19] studied the effect of surge furrow irrigation compared with continues irrigation on water management at different plouphing methods, showed that, surge flow treatments required less time for completion the advance phase than with those continuous flow treatments at different plouphing treatments. Varlev *et al.* [20] found that surge irrigation required 20-25% less water than continuous irrigation, whereas deep percolation decreased from 12-15% to 6-8% while run off losses reduced from 25-30% to 10-12% by using surge irrigation. Surface flooding irrigation by furrows is the most widely used irrigation method in the clay soil. Studies done at the Malheur Experiment Station and elsewhere have shown significant benefits to surge irrigation: (1) More uniform application of irrigation water (2) Reduced water use through reductions in deep percolation and runoff (3) Reduced costs through reductions in water use and labor (4) Reduced nitrogen leaching (5) Reduced sediment loss (6) Reduced surface water contamination [21].

The advantages of surge flow surface irrigation fall into three broad categories [22]. Surged water advances to the end of the field at least as rapidly as continuous flow irrigation with the same inflow rates but with a smaller volume of water, thus greatly improving the uniformity of application during the advance phase. b) Growers can reduce tail water and deep percolation losses and can improve application efficiencies under proper automated management. c) Surge irrigation provides an inexpensive means of automating, managing and accurately controlling the surface application of water to a field while reducing labor requirements [22]. Surge irrigation is one of the famous methods in irrigation management and has been studied in many articles, which some of them will be described in the following. Mostafazadeh-Fard *et al*. [23] developed and evaluated an automatic surge irrigation system in furrow irrigation. The results showed that the system was able to accurately and automatically irrigate the furrows by surge method based on information were given to the system. For the same discharge and volume of water applied to the furrows the water advance along the furrows were faster for surge flow as compared to the continuous flow. Valipour and Montazar [24] determined number of required observation data for rainfall forecasting to agricultural water management. Rodríguez *et al.* [25] compared surge irrigation and conventional furrow irrigation for covered black tobacco cultivation in a Ferralsol soil. The surge flow furrow irrigation with variable time cycles increased the application efficiency by more than six fold and the water volume was reduced by more than 80% compared to continuous irrigation. The largest rises in distribution uniformity and reductions in percolation losses were obtained with a furrow length of 200 m and a discharge of 1 liter per second, respectively. Sial *et al.* [26] studied performance of surge irrigation under borders. Keeping in view different parameters like volume of water, distribution uniformity, application efficiency, deep percolation losses and yield of wheat, the surge mode of irrigation was convincingly better compared with conventional/continuous irrigation even under the border irrigation. Jensen and Shock [27] considered surge irrigation or at last a modified surge program on the first irrigation as a strategy for furrow irrigation.

Many farmers were done about the effect of land slopes. El-Saadawy and Abd El-Latif [28] indicated that under 0.1% slope the infiltration opportunity better than the traditional methods and the infiltration rate was very high with the traditional and leveling. Data revealed that the traditional methods received more amount of water than 0.1% slope. The amount of water for different treatments 100, 75 and 50 m irrigation border with 0.1% slope were 2821.25, 2588.46 and 2293.79 m^3/faddan

(one faddan= 0.42 ha), respectively. Doorenbos and Pruit [29] recommended that land slopes should be ranged 0.05 and 0.2% depending on furrow stream size; longer borders may require some land slopes to option efficiency irrigation. Dedrick [30] reported that length of a basin (unit area) is dependent on the infiltration characteristics of the soil, the resistance to flow, the desired distribution uniformity, the nit depth of application and unit flow rate. Distribution uniformity on level basins tends to increase as rate of advance increase and rate of advance increase as resistance to flow and infiltration decrease. Maize is a very important grain and fodder crop in all over the world. It ranks the third after wheat and rice in Egypt. Recently, the demand for grain food is continuously increasing. Therefore, the aim of this present study is to improve the furrow irrigation system using Alternative furrows irrigation and surge irrigation for maize cultivated in order to save water and to increase water use efficiency.

MATERIALS AND METHODS

Experimental Site: Tow field experiments were conducted at the farm of El-Karada Water Management Research Station, Kafr El-Sheik Governorate, during the two successive summer seasons 2012 and 2013. The physical and chemical properties of soil sites for the two experiments were determined according to Klute [31] and Westerman [32] as presented in Tables 1 and 2. Seeds of Maize (*Zea mays* L. cv. TWC 310) were sown on June 5, 7 at the rate of 12 kg/faddan (one faddan = 0.42 ha). The recommended phosphorus fertilizer was added to all plots during the preparation soil in the rate of 15 kg P_2O_5/faddan, while nitrogen fertilizer was applied in the form of urea (48.5 N %) at the rate of 150 kg N/faddan in three equal portions, the 1st at 21 days after sowing (DAS), the 2nd at 45 DAS and the 3rd at 15 days later. The experimental area has an arid climate with cool winters and

Table 1: Monthly and growing season climatic data of the experimental site

Date	Solar radiation Dgt (m J/m²) Average	Wind direction dig (deg) Last	Precipitation (mm) Sum	Wind speed (m/sec) Average	Maximum	Air temperature (°C) Average	Minimum	Relative humidity (%) Maximum	Average
6/1/2012	424.36	186	0.4	0.72	3.9	25.04	17.33	35.91	69
7/1/2012	401.7	135	9.4	0.71	3.2	27.1	19.85	36.14	74
8/1/2012	339.82	115	0.8	0.7	4.0	26.75	20.83	34.7	74
9/1/2012	271.87	144	1.4	0.45	3.8	25.78	18.83	34.32	73
10/1/2012	184.22	136	0.0	0.43	3.9	22.31	14.28	37.6	65
6/1/2013	360.51	144	0.2	0.64	3.5	28.35	21.02	36.89	75
7/1/2013	297.89	127	1.8	0.59	3.4	27.9	20.04	36.2	74
8/1/2013	224.49	39	0.0	0.43	3.2	25.72	18.89	34.94	71
9/1/2013	152.39	325	6.2	0.39	3.5	23.81	15.69	32.28	74
10/1/2013	100.31	272	14.8	0.38	3.6	19.9	12.05	29.42	82

Table 2: Mechanical soil analysis and soil moisture content of experimental sites at different depths.

Soil depth(cm)	Soil moisture content Bulk density g/cm³	Field capacity (%)	Permanent witling point (%)	Physical Properties Sand %	Fine sand %	Silt %	Clay %	Soil texture
0 -20	1.11	50.62	28.07	1.60	14.40	19.7	64.70	Clay
20 -40	1.28	46.11	26.12	1.80	14.90	17.10	66.20	Clay
40 - 60	1.33	45.20	31.00	1.80	13.20	16.00	69.00	Clay

Table 3: Chemical properties of the experimental soil sites.

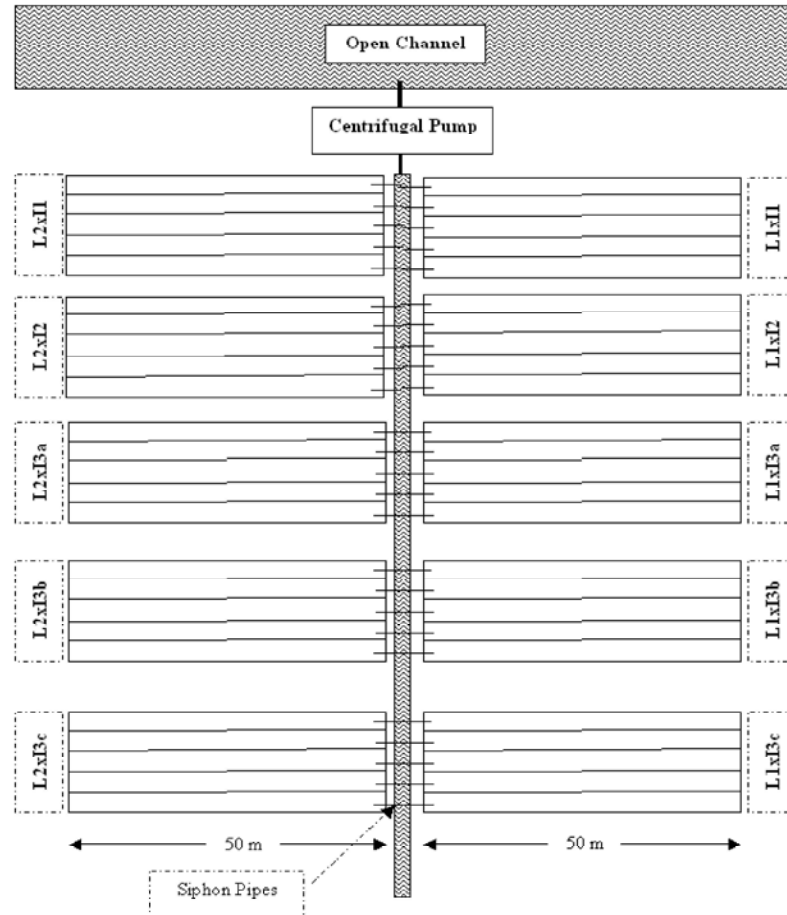| Soil depth (cm)	pH	EC mmhos/cm	Soluble cation (ppm) Ca⁺⁺	Mg⁺⁺	K⁺	Na⁺	Soluble anion (ppm) Cl⁻	CO₃⁻	HCO₃⁻	SO4⁻
0 -20	8.1	2.1	5.64	5.0	0.36	9.0	11	-	3.4	6.76
20 -40	8.1	2.1	4.73	4.0	0.37	12.0	13	-	6.1	2.07
40- 60	8.3	2.7	5.00	6.4	0.34	14.8	13	-	5.1	8.54

Fig. 1: Layout of Experiment Design.

[Slope of zero% = 0cm/100m length (L_1) & 10cm/100m length (L_2)]. [Continuous flow irrigation, for all furrows (I_1) & Alternative furrows irrigation (I_2) and Surge Irrigation cycle ratio was as the follows: (I_{3a}) ratio with 50% {9 min on and 9 min off}, (I_{3b}) ratio with 66% {9 min on and 6 min off} and (I_{3c}) ratio with75% {9 min on and 3 min off}

hot dry summers prevailing in the experimental area. Table 1 summarizes the monthly mean climatic data for the two growing seasons 2012 and 2013, respectively. The data of maximum and minimum temperature, relative humidity and wind speed were obtained from The Central Laboratory of Meteorology which is related to Ministry of Agriculture, Egypt. There was not rainfall that could be taken into consideration through the two seasons, because the amount was very little and the duration didn't exceed few minutes.

Experimental Details: Soil samples were collected before and two days after each irrigation from three layers (0-20, 20-40 and 40-60 cm) each to determine soil moisture content, field capacity and bulk density was determined according to Michael [33] and Vomocil [34], respectively

as presented in Table 2 while, chemical properties of the experimental soil sites at Kafr El-Sheikh Governorate Egypt are presented in Table 3.

Experiment Design: The experiments were arranged in strip-plot design with four replicates. The main-plot represented land leveling methods [slope of zero% = 0 cm/100 m length (L_1) & 10 cm/100 m length (L_2)]. While, the sup-plot treatments represented water applied methods, e.g. [Continuous flow irrigation, for all furrows (I_1) & Alternative furrows irrigation (I_2) and surge irrigation with different cycle ratios (I_3)]. Surge Irrigation cycle ratio was as the follows: (I_{3a}) ratio with 50% {9 min on and 9 min off}, (I_{3b}) ratio with 66% {9 min on and 6 min off} and (I_{3c}) ratio with75% {9 min on and 3 min off} (Fig. 1).

Data Recorded:

Water Applied (Q): Discharge measurements were made by using a fixed crested weir using its Empirical equation according to Masoud [35] as follows:

$$Q = cL.H^{3/2}$$

Where:

(Q) discharge in cubic meter per minuet, (L) length of the crest in meter, (H) water head in meter, (C) discharge coefficient.

Water Distribution Efficiency (DU (%): DU was calculated by Hansen *et al.* [36] by the following equation:

$$DU = 100 (1-Y/D)$$

Where:

(DU) Water distribution efficiency, %, (Y) average numerical absolute deviation of soil moisture. (D) Average soil moisture content stored as computed at a certain time of irrigation.

Grain Yield: At harvest time (on October 25, 29 in 2012 and 2013 seasons, respectively), plant of tow meter length of row were taken at random from the fifth inner row for each sub-plots for determining: grain yield. Grain yield was determined at grain moisture content about 15%, then converted to estimate grain yield in kg/faddan.

Irrigation Water Use Efficiency (IWUE): IWUE was calculated by Michael [33] as the following equation:
$$IWUE = Y/WR$$

Where:

(Y) Grain yield (kg/faddan), (WR) total amount of water used in field (m³/faddan).

Statistical Analysis: Data of the two seasons were statistically analyzed according the procedures of Snedecor and Cochran [37] and Waller and Duncan [38].

RESULTS AND DISCUSSION

Total Amount of Irrigation Water Applied: Data in Table 4 indicated that effect of study factors on total amount of irrigation water applied. First of all, effect of land leveling and second, effect of water applied methods and finally, effect the interaction between land leveling and water applied methods on total amount of irrigation water applied.

Effect of Land Leveling: Data in Table 4 indicated that increasing slope lead to decrease amount of water applied. It caused increase speed of water on soil surface and decrease water percolation in soil layer. Where as, slope (0%) treatment overcame in amount of water applied than slope 0.01%. Where, 2470.73 and 2427.33 m³/faddan, respectively. This result is in agreement with those obtained by El-Saadawy and Abd El-Latif [28] and Doorenbos and Pruitt [29].

Effect of Water Applied Methods: Data in Table 4 showed that, the lowest value of total amount of irrigation water applied was 1811 m³/faddan under alternative irrigation method and this is due to alternative irrigation method depending on irrigate one furrow and leave the other this mean, half of total amount of irrigation water applied were applied only compared with the other methods. Also, increasing the surge cycle ratio led to decrease amount of water. On the other side, there were not significant different between surge cycle ratio at 0.5 and 0.66.

Effect the Interaction Between Land Leveling and Water Applied Methods: Data in Table 4 showed that, the lowest value of total amount of irrigation water applied was 1784 m³/fed. under the following conditions (alternative irrigation method and slope 0.01% and this is due to tow reasons, first of all, slope 0.01% increase from speed of irrigation water on soil surface and decrease water percolation in soil layer. The second, alternative irrigation method depending on irrigate one furrow and leave the other this mean, half of total amount of irrigation water applied were applied only compared with the other methods.

Water Distribution Efficiency%: Table 4 illustrate the increasing slope led to increase distribution efficiency (DE), where value it was 94.2% with slope 0.1 while 93.8% with slope 0. on the other side, increasing time of surge cycle ratio led to increase DE value so, the highest value recorded by surge cycle ratio at 0.75 it was 97.33% while the lowest value recorded by continuous irrigation it was 90.33% Significant interactions were deflected between slope and water applied methods in both seasons. This result is in agreement with those reported Dedrick [30].
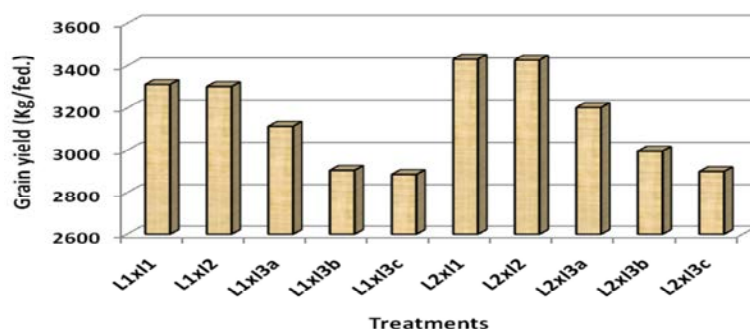
Fig. 2: Effect of interaction between land leveling and water applied methods on grain yield.
(I_1): Continuous flow irrigation, for all furrows, (I_2): Alternative furrows irrigation (I_{3a}) : Surge Irrigation cycle ratio was 0.5 (I_{3b}) : Surge Irrigation cycle ratio was 0.66 (I_{3c}): Surge Irrigation cycle ratio was 0.75
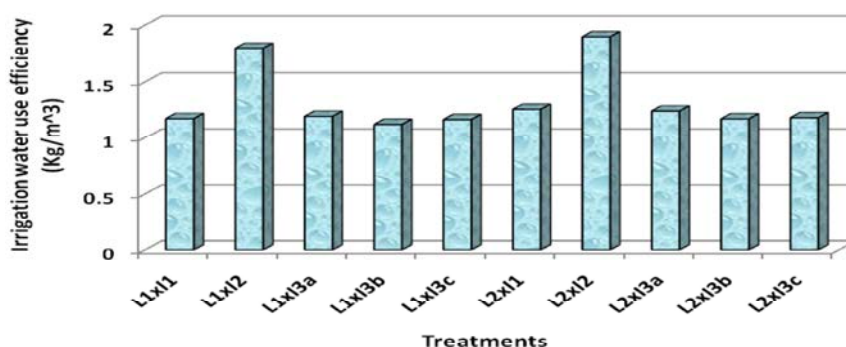

Fig. 3: Effect of interaction between land leveling and water applied methods on irrigation water use efficiency.

Table 4: Effect of land leveling and water applied methods on total amount of applied water, distribution efficiency, grain yield and irrigation water use efficiency (Average of two seasons).

Treatments	Total amount of applied water (m³/faddan)	Distribution efficiency (%)	Grain yield (Kg/faddan)	Irrigation water use efficiency (Kg/m³)
Land leveling				
L1	2470.73 a ± 347.52	93.80±2.27	3103.93 b±190.54	1.289 b±0.264
L2	2427.33 b ± 345.74	94.20±2.65	3183.40 a±216.18	1.347 a ±0.287
LSD at α 0.05	4.33	N.S	6.17	0.005
Water applied methods				
I1	2784.50 a ± 48.16	90.50e±0.55	3371.50a±65.22	1.212b ±0.044
I2	1811.00e ± 29.59	92.17d±0.75	3369.17ab±46.42	1.848a ±0.056
I3a	2602.00b ±13.91	94.83c±0.41	3158.50c±48.77	1.214b ±0.025
I3b	2577.33c ±15.37	95.83b±0.75	2951.17d ±49.90	1.145d±0.026
I3c	2470.33d ± 12.09	96.67a± 0.82	2893.00e ± 7.87	1.171c ±0.009
LSD at α 0.05	2.453	0.642	3.869	0.003
Interaction				
$L_1 x I_1$	2828.3A ± 1.35	90.33±0.58	3312.00c ± 2.83	1.171g ±0.002
$L_1 x I_2$	1838.00h ± 1.00	92.33±0.58	3302.00d ± 2.00	1.797b ±0.002
$L_1 x I_{3a}$	2614.67c ± 1.15	94.67±0.58	3114.00f ±1.00	1.191e ±0.001
$L_1 x I_{3b}$	2591.33d ± 1.53	95.67±0.58	2905.67h ± 2.42	1.121i ±0.001
$L_1 x I_{3c}$	2481.33f ±1.53	96.00±0.00	2886.00j±2.00	1.163h ±0.002
$L_2 x I_1$	2740.67b ± 5.77	90.67±0.58	3431.00a ± 2.12	1.252c ±0.003
$L_2 x I_2$	1784.00i ± 1.00	92.00±1.00	3427.33ab ±7.06	1.898a ±0.005
$L_2 x I_{3a}$	2589.33d ±1.53	95.00±0.00	3203.00e ±2.12	1.237d ±0.001
$L_2 x I_{3b}$	2563.33e ± 0.58	96.00±1.00	2996.67g ± 3.06	1.169g ±0.002
$L_2 x I_{3c}$	2459.33g ± 0.58	97.33±0.58	2900.00i ±2.00	1.179f ±0.001
LSD at α 0.05	3.469	N.S	5.471	0.0041

(I_1): Continuous flow irrigation, for all furrows,(I_2): Alternative furrows irrigation, (I_{3a}):Surge Irrigation cycle ratio was 0.5, (I_{3b}) : Surge Irrigation cycle ratio was 0.66 (I_{3c}): Surge Irrigation cycle ratio was 0.75

Grain Yield: Data in Table 4 indicated that effect of study factors on grain yield. First of all, effect of land leveling and second, effect of water applied methods and finally, effect the interaction between land leveling and water applied methods on grain yield. Significant interactions detected between slope and different irrigation system in the two seasons.

Effect of Land Leveling: Data in Table 4 indicated that increasing slope lead to increase grain yield. It caused increase speed of water on soil surface and decrease water percolation in soil layer hence, improving from water distribution in root zoon. Slope 0.1% treatment gave the best value of grain yield. It was 3183.4 kg/faddan.

Effect of Water Applied Methods: Data in Table 4 showed that, the highest value of grain yield was 3371.5 kg/faddan under continuous irrigation and no significant between continuous irrigation and alternative irrigation method. These results are in accordance with other studies in literature [5-22].

Effect the Interaction Between Land Leveling and Water Applied Methods: Fig. 2 and data in Table 4 illustrated that, the highest value of grain yield was 3431 kg/faddan under the following conditions (continuous irrigation method and slope 0.01% and this is due to tow reasons, first of all, slope 0.01% increase from speed of irrigation water on soil surface and decrease water percolation in soil layer. Hence, improving from water distribution in root zoon. The second, the advantages of alternative irrigation method technique did not equivalent the shortage of irrigation water because alternative irrigation method depending on irrigate one furrow and leave the other this mean, half of total amount of irrigation water applied were applied only compared with the other methods.)

Irrigation Water Use Efficiency: Data presented in Table 4 and Fig. 3 revealed that in increasing IWUE with slope (0.01%) and the highest value of IWUE were 1.898 kg/m^3 under L2xI2, while IWUE was 1.121 kg/m^3 under L1XI3b.

CONCLUSIONS

Alternative irrigation method with slope 0.01% produced the highest values of irrigation water use efficiency.

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