ENHANCING FURROW IRRIGATION PERFORMANCE AND WATER PRODUCTIVITY THROUGH BETTER DESIGN AND WATER MANAGEMENT IN A CRACKED SOIL

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ABSTRACT

Furrow irrigation is widely used because of its low cost and energy requirement, but less efficient compared with the pressurized irrigation systems. Management of water resources in Vertisols is more problematic compared to other soil groups. This soil is representing a vast crop production resource and account for a considerable portion of the region under study. The preferential flow has a profound effect on the performance furrow irrigation in cracked soils. Accordingly, itis of vital importance to select the most appropriate management practices to improve the performance of surface irrigation in these soils. Accordingly, a series of field experiments were conducted over a cracked soil at a research farm located in the outskirt of Sulaimani city during the summer seasons of 2017 and 2018 with furrow lengths in the range of 30 to 70 m. The main objectives were to improve the performance of furrow irrigation and water use efficiency of eggplant by changing furrow shape and length by application different irrigation techniques .The results indicated that irrigation efficiency tended to increase by reducing furrow length, by decreasing available water depletion and by changing the furrow shape. Overall, the applied irrigation treatments can be ranked according to the degree of their effectiveness in term of irrigation performance, eggplant fruit yield and water use efficiency as follows: Surge flow > Fixed furrow irrigation > Alternate furrow irrigation > Cutback > continuous flow.

Keywords: surge flow, cutback, alternate furrow irrigation, water use efficiency.

تحسين أداء الري بالمروز و إنتاجية المياه من خلال أفضل تصميم وإدارة المياه في تربة متشققة

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المستخلص

يعد الري بالمروز من الطرق الشائعة للرى بسبب انخفاض الكلفة ومتطلبات الطاقة ولكنه أقل كفاءة مقارنة بأنظمة الري الحديثة. و تكون اشكالية انخفاض كفاءة الرى اكثر وضوحا فى الترب متشققة Vertisols مقارنة بالترية الأخرى. تمثل هذه الترب موردًا كبيرًا لإنتاج المحاصيل وتشكل جزءًا كبيرًا من المنطقة قيد الدراسة. و للتدفق التفضيلي تأثيركبير فى أداء الرى في الترية المتشققة، وعليه يجب البحث عن أنسب الممارساتالتصميمية و الإدارية المتعلقة باستخدام المياه لتحسين أداء الري السطحي في هذه الترب.وفقًا لذلك اجريت سلسلة من التجارب الحقلية على تربة متشققة في مزرعة للأبحاث تقع في ضواحي مدينة السليمانية خلال موسمى الصيف 2017 و 2018 لمروز ذات أطوال تتراوح مابين 10 و 70 م. وكانت الأهداف الرئيسية تحسين أداء الري بالمروز وكفاءة استخدام المياه لمحصول الباذنجان من خلال تغيير شكل المرز وطول المروز ومن خلال تطبيق معاملات ري مختلفة. أشارت النتائج إلى أن كفاءة الري تميل إلى الازدياد عن طريق تقليل طول، وخفض إستنزاف الماء الجاهز وتغييرشكل مقطع المروز.وبشكل عام يمكن ترتيب المعالجات المطبقة وفقًا لدرجة فعاليتها من حيث أداء الري وإنتاجية محول الباذنجان وكفاءة استخدام المياه على النحو التالي: الجريان الموجى > ري ثابت> ري متناوب> قطع رجعى> جريان مستمر.

كلمات مفتاحية:القطع الرجعى، الرى النبضى، الرى البديل، وكفاءة استخدام المياه.

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INTRODUCTION

The water scarcity is growing rapidly due to increased demand for water from all water consuming sectors (28). Intensification of agricultural activities and increasing water consumption for household and industrial purposes (17) besides the climatic change are the main factors aggravating the intensity of water shortage. Howell (11) and Wang et al. (38) reported that the use of conventional irrigation methods along with improper irrigation management can lead to large water losses in agricultural fields. Hence, the irrigation efficiency becomes a crucial aspect of irrigated agriculture and a key factor due to the competition for water resources (22). Irrigation performance is closely connected with irrigation management than structural issues (5). This strategy constitutes a striking method to mitigate water scarcity in the Mediterranean countries (32). Vertisols represent a vast crop production resource and account for a considerable portion of the intermountain valley soils in Iraqi Kurdistan region. Management of water resources in Vertisols is more problematic compared to other soil groups. When the soils of this group dry, cracks are formed and these cracks facilitate rapid transport of surface water into the subsoil through preferential flow (6). Jafari (15) evaluated the irrigation management in a silty clay paddy soil using three levels of crack width and three depths of irrigation water to refill cracks. The result of this study indicated that initial soil moisture content has a significant effect on the rate of water infiltration in cracked soils, and a major part of irrigation water is spent for filling the cracks in the beginning of infiltration process. Surge irrigation known intermittent irrigation or surge flow (34) can be regarded as one of the most efficient strategies for applying irrigation water (29). Ismail (13) reported that during the first off-time period, the furrow is dewatered and the intake rate of the furrow is reduced, hence more water is available in the dry parts of the furrow when water is admitted during the second surge. His findings also showed that the reduction in advance time is more prominent for high than low discharge rate and more in course than in fine textured soils. Furthermore, it was shown that effectiveness of surge flow increases with an increase in off-time period. Processes are responsible for infiltration reduction during surge irrigation is consolidation; air entrapment, redistribution of water and hysteresis (35). Alternate furrow irrigation as a management strategy can also reduce water losses in form of deep percolation and runoff by facilitating lateral water movement (31). This irrigation technique has potential to retain fertilizer in the root zone for plant uptake, thus giving rise to lower chemical pollution of ground water by nitrate and phosphorus in water bodies (7). Mohammed et al. (24) demonstrated that by applying cutback system, water losses due to runoff can be avoided from the far end of the furrow. This system aims at minimal water losses trade-off between deep percolation and tail water runoff (23). According to this concept, initially, a large non-erodible steam size is applied to reach the furrow far end during a short time, and then the stream size is reduced to be close to the soil basic infiltration rate (37). Issaka (14) evaluated the performance of field application techniques under furrow irrigation and observed that the performance was ranked in following order: Surge > Cutback > Cutoff > Bunds. The awareness toward the nutritional and health benefit of vegetables such as eggplant in fulfilling the nutritional requirement of the family has been increased. This is giving rise to increased cultivation of this type of crop to go along with the rapid growth of population (18).Fine roots have ability to absorb water and nutrients, whereas coarse roots are more rigid, anchor the plant to the soil, and provide the structural skeleton that supports the fine roots (44). Ayas (3) reported that the yield, yield attributes and biomass production of vegetable crops like eggplant are highly affected by optimal amounts of irrigation water supply. In view of above facts, the current study was conducted aiming at improving the performance of furrow irrigation and water use efficiency of eggplant under different irrigation treatments and by adopting better designs.

MATERIALS AND METHODS

Study site description

The experimental site is situated in the outskirt of Sulaimani city. The field is adjacent to the

Qaragol Bridge within the administrative border of Arbat County. It is located about 20 km northeast of the Sulaimani city center and about 2 km to the south of Arbat County. The geo-position of the experimental site is $35^o\ 44^{'}\ 05^{''}$N and is $44^o\ 30^{'}\ 25^{''}$E, lying 760 m a.s.l. The total area of the field is 4.5 ha and affiliated the Directorate of Sulaimani Agricultural research. Typical Mediterranean climatic conditions with intensive storms in spring and dry spells in summer are prevalent in most of the areas surrounding Sulaimani city. Mean annual precipitation (1985-2018) across the study ranges between 500 and 900 mm distributed over rainy months. It has a unimodal distribution with an average value of 700 mm. Further, the annual distribution shows a dry season lasting from June to September and a wet season from October to April. Temperature is lowest during December and January with mean minimum of 5^oC and highest during July and August with mean maximum of 38^oC. On the basis of aridity index (AI) defined as the ratio of mean annual precipitation to potential evapotranspiration, the climate regime can be classified as semiarid ($0.2>AI<0.5$) (38). The aridity index according this scheme is 0.23. Further, it can be classified as a temperate, dry summer, hot summer (Csa) according to the scheme proposed by Koppen. The soil of surface layer has a brownish colour grading into brownish to whitish horizons of lime accumulation due to leaching of lime from the surface overlying layers (4). According to soil taxonomy (33), the soil at the experimental site is categorized as Fine Clay, Active, Mixed, Thermic, Typic Chromoxerets. The soil textures are predominantly silty clay loam and silty clay. As a whole, the soil of the site is deep. Average soil depth is more than 1 m. Soil reaction is basic and Organic matter content is generally medium, with values of more than 2%.With no exception, all the existing soils are non-saline and calcareous. The equivalent $CaCO_3$ content ranges from about 20% to more than 40%. The soil of the site is nearly free of rocks (clay=40.5%; silt=52.5% and sand=7%; EC_e = 0.57 dSm^{-1}). Furthermore, the soil has relatively a high potential to volume change, which is manifested by wide and deep crakes during the summer season. The coefficient of linear extensibility is in the range of 10 -12%.

Field experiments

Land preparation

Land preparation was carried out with a moldboard plow to a depth of 0.30 m, followed by disc harrowing to break the clods and firm the top soil. Afterwards, the field was graded to a furrow slope of about 1.5%. The research field was then subdivided into plots. Each plot had its own dimensions and utilized for different experiments.

Irrigation schedule

The irrigation schedule was based on available water depleted at 40 % (1). The soil moisture content was monitored gravimetrically by using a small auger. The source of water was the Tanjarow river (EC = 0.57dSm^{-1}) which situated to the south of the field.

Furrow specification

The furrows were rebuilt to create identical furrows with uniform dimensions and longitudinal slope. The furrow length varied between 10 and 70 m with an average depth of 0.25 m. The top width was about 0.6 m, while the side slope was 1:1. Further, the longitudinal slope was 0.015 m m^{-1}. Unless otherwise stated, the experiment furrows were blocked on the downstream ends.

Experimental setup

everal experiments were conducted during the summer seasons of 2017 and 2018 using furrows with lengths in the range of 10 – 70 m. Each experiment was laid out in a completely randomized block design (RCBD) with three replications. (Surge 1/3, Surge 2/3, Surge1, Fix Furrow Irrigation (FFI), Alternate Furrow Irrigation (AFI), Every Furrow Irrigation (EFI), With Cutback Irrigation, Without Cutback Irrigation, Depletion 25 (D_p= 25%, Depletion 50 (D_p= 50%, Depletion 75 (D_p= 75%, Depletion 100 (D_p= 100%). Each experimental furrow was provided with two guard rows on either side. Treatments were allocated in accordance with the randomization.

Planting and other cultural practices

Prior to transplanting, seeds of eggplant plant (Species: MELANZANA, Varity: VIOLETTA) were sown in a nearby nursery subsequently, the seedlings were transplanted into the furrows on May 8^{th} in 2017. The seedlings were transplanted at the furrow crest at spacing of 0.60 m on both sides of the ridges. The ridge top center spacing was 0.75m. The eggplant received a basal application of 25 kg N and 225 kg P in form of urea and single superphosphate, respectively. Three irrigations were applied until the seedlings were well established. Weeds were removed manually three times during the growing season.

Advance time measurement

Representative furrows under each treatment were divided into a number of stations having equal distances between them by driving metal mark into the soil at 3 m interval along its length. V-notch weir was installed to supply water at a rate of 0.4 Ls^{-1}.As the irrigation, water was advanced down the furrow arrival times were recorded at the end of each station using a stopwatch. The advance time was measured during the applied irrigation events.

Performance indictors

The performance of irrigation treatment was evaluated after computing each of irrigation application efficiency (Ea) (43):

$$E_a = \frac{ds}{d_{app}} 100$$

Where: ds = Depth of stored water in the root zone (mm)

d_{app} = Depth of applied water (mm).

and distribution efficiency (Ed) (10):

$$E_d = \left[1 - \frac{\sum |dev|}{d_{app}}\right] 100$$

Where: dev = deviation of depth of infiltrated water from the mean value.

Crop yield and field water efficiency

The total marketable yield was computed after picking up the crop every 5-7 days under each treatment. Additionally, the following formula was used to calculate the field water efficiency (16):

$$WUE = \frac{Y}{d} x1000$$

Where Y = Crop marketable yield (T ha^{-1})

d = Volume of applied water ($m^3 ha^{-1}$)

WUE= water use efficiency (kg m^{-3})

RESULTS AND DISCUSSION

Effect of depletion percentage on rate of advance time: The plot of traveled distance versus advance time during three successive irrigation in Fig.1 indicates that wave-front advance along the furrows follows a quasi-linear form. The time required for water to arrive at a given station increased steadily with an increase in the percent available water depleted. The wetfront advance exhibited similar trends for furrows with lengths of 30 and 70 m. Fig.1 also displays the time required for water to reach lower the end of furrows with lengths of 30 and 70 m during three successive irrigations as affected by percent of depletion of available water. The results indicated that there is a steady decrease in advance time with decrease in the percent of available water depletion. Close examination of Table 1 also revealed that there is a substantial increase in the time required for water to advance down the furrow increases with increase in furrow length. Furthermore, It can be noticed that the advance time is taken by water to reach the lower end of the furrows under 25, 50 and 75% available water depletion reduced by 41.53, 24.67 and 15.05% compared to that under a 100% of available water depletion respectively when the furrow length was 30 m. This might be due to more reduction in deep percolation losses with increase soil water content prior to irrigation. The effectiveness of depletion percent tended to decrease with increase in furrow length. For the length of 70 m, the percent of the reduction under depletion percent of 25, 50 and 75% were 31.53, 23.82 and 14.65% compared to that under 100% of available water depletion respectively. Shorter advance times yielded a more uniform infiltration profile along the length of the furrow.

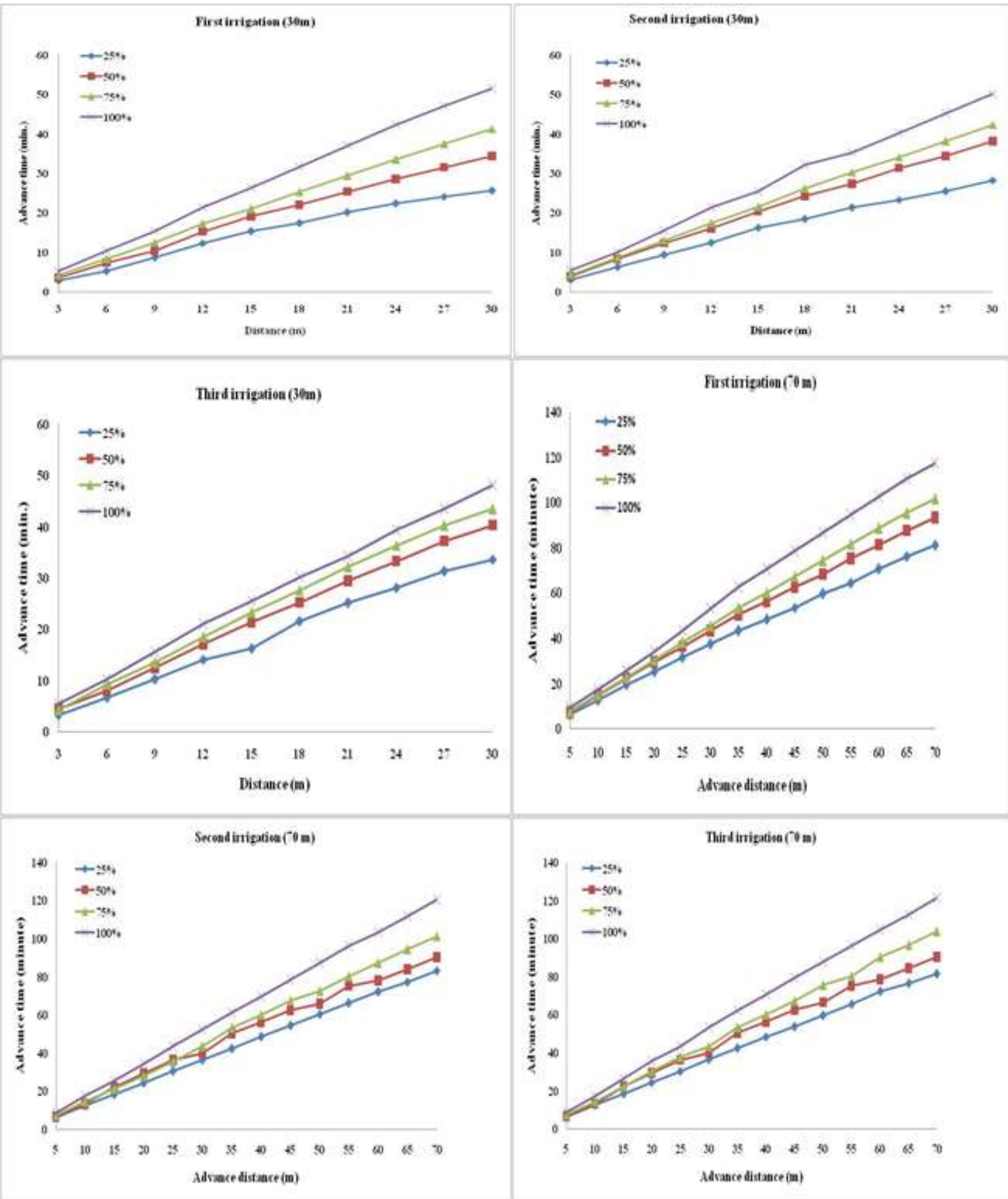

Fig1. Advance time as influenced by percent available water depletion for furrow lengths of 30 and 70m

Table1. Percent of reduction in advance time as influenced by percent of available water depletion and furrow length

Available water depletion	Percent of reduction in advance time	
	30 m	70 m
25 %	41.53	31.53
50 %	24.67	23.82
75 %	15.05	14.65
100 %		

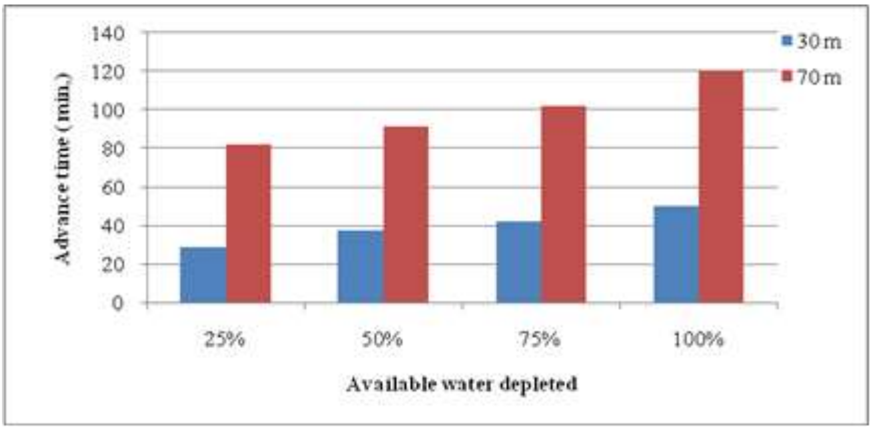

Fig 2.Advance time as affected by depletion percent of available water

Effect of furrow shape on irrigation performance

As seen from Fig.3, there is an improvement in irrigation performance upon replacing the U-shaped cross-section of the furrows by the V-shaped one. The irrigation application efficiency increased from 65.71 to 75.41%, while the uniformity coefficient increased from 85.63 to 90.75%. The percentage of increase in actual evapotranspiration (E_a) and (C_u) were 14.76% and 5.98% due to change the furrow geometry from a U shaped to a V-shaped cross-section. The reason was presumably due to a smaller wetted perimeter available for infiltration in V-shaped furrows. This practice has an important implication for reducing the volume of water applied, reducing the time to conduct irrigation cycles and for reducing the energy spent during pumping (27).

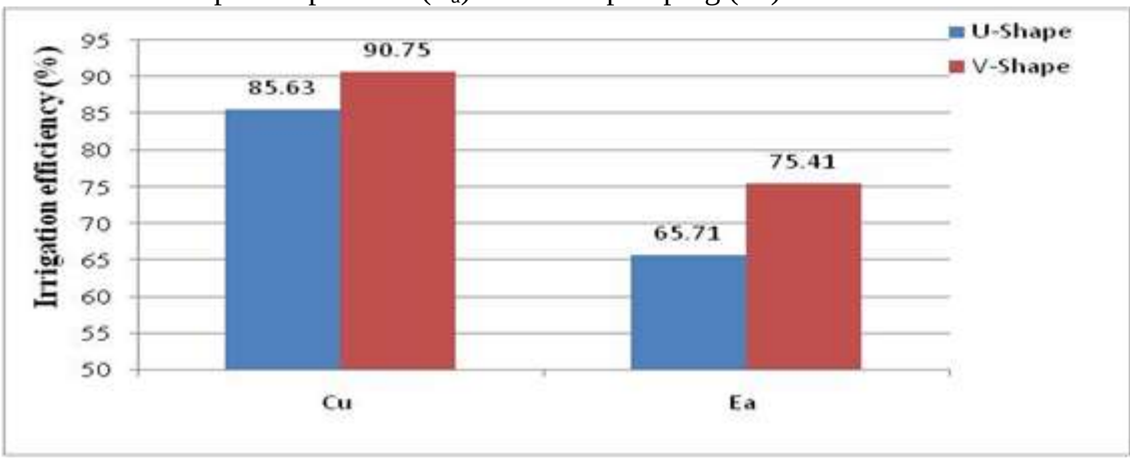

Fig3. Furrow irrigation performance as influenced by furrow shape

Effect of furrow length on irrigation performance

The results presented in Fig.4 indicates that there is a steady increase in both irrigation application efficiency and uniformity coefficient with a decrease in length of furrow during an experiment without cropping in the cracked soil. Based on the obtained results, it is not recommended to apply furrow lengths greater than 200 m, under this length the irrigation application and uniformity coefficient drop to less than 70% and 80% respectively. Under short furrows, the variation in slope, furrow dimensions and contact time are very low as compared to longer furrows. As a result, more uniformity occurred in shorter furrows and there was a negative relationship between and furrow length and uniformity coefficient (42). Since this result agrees with (39 and 40), they revealed that using a shorter length of run can reduce both deep percolation and runoff, consequently increase irrigation efficiency. By contrast, it increases the labor and management costs. The results also agreed with Assefa et al., (2) which found that higher efficiencies achieved for small furrow lengths with relatively low discharges and larger flow rates are needed as furrow length increases to obtain high efficiencies.

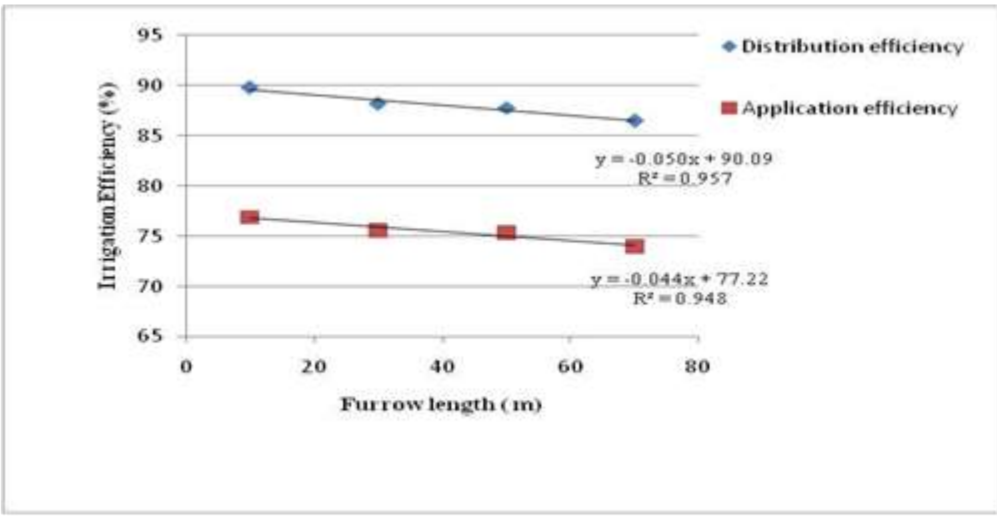

Fig4. Irrigation efficiency as influenced by furrow length

Effect of alternate Irrigation on Irrigation Performance

Fig.5 displays the effect of adopting alternate furrow irrigation on irrigation performance in the investigated cracked soil cropped with eggplant during the summer season of 2017 using furrows 30 m in length. It was obvious that the fixed furrow irrigation (FFI) offered the highest performance followed by the alternate furrow irrigation (AFI) compared with every furrow irrigation (EFI). This means that the performance of various treatments followed the order:

FFI > AFI > EFI

The results also indicated the effect of the applied treatments was more profound on irrigation application efficiency (Ea) compared with their effects on distribution efficiency (Ed). The percents of increase in Ea under FFI and AFI were 12.51 and 8.60% compared with Ea for EFI respectively, while the percent of increase in Ed under these two treatments were 8.58 and 5.4% respectively. According to analysis of variance, there is significant difference between the performance of the three irrigation systems in term of Ea and Ed at ($p \leq 0.05$). The result of Ed is not consistent with Woldesenbet (41) who observed that the distribution uniformity was not affected by these of treatments.

Effect of alternate irrigation on use efficiency

Lower eggplant yield from both fixed furrow irrigation and alternate furrow were obtained as compared to conventional furrow irrigation (every furrow water application) (Table 2). The reduced evapotranspiration in the alternate furrow irrigation method is due to a reduction of wetted soil surface area compared to every furrow irrigation (36).

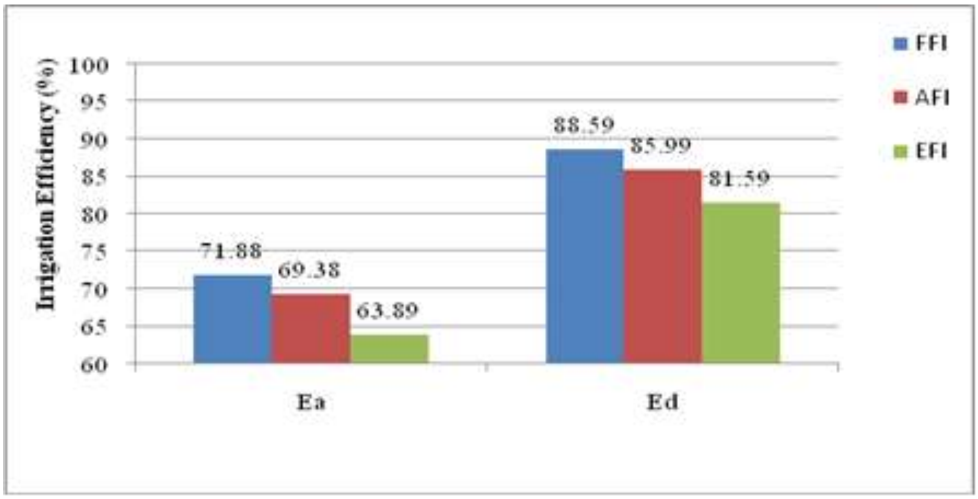

Fig5. Effect of alternate furrow irrigation on irrigation performance in a cracked soil cropped with eggplant during the summer season of 2017

In terms of the marketable fruit yield, the highest yield was obtained from the EFI treatment as 43.66 t ha^{-1}, while the lowest fruit yield was obtained from the AFI treatment as 28.03 t ha^{-1}. The highest amount of irrigation water was applied under the EFI as 502.0 mm through 12 successive irrigations during the growing season, while the lowest amount of irrigation water was applied under the remaining treatments as 306.2 mm. It is obvious from the presented results in Table 2 that the irrigation water efficiency ranged between 8.7 and 10.55 kg m^{-3}. The fixed furrow irrigation (FFI) treatment offered the highest water efficiency followed by the AFI compared to that under EFI treatment. This order of effectiveness was unexpected and may due to presence of intensive cracks.

Table2. Eggplant water efficiency as influenced by alternate irrigation

Treatment	Yield (kg ha^{-1})	Volume of applied water (m^3)	Water use efficiency (k gm^{-3})
Fix	32.31	3062.00	10.55
Alternate	28.03	3062.00	9.16
Control	43.66	5020.00	8.70

The obtained values for IWE were in concordance with results obtained by Ayas (3), who observed that the irrigation water efficiency for eggplant fell under different irrigation treatments in the range of 5.17-10.63 kgm^{-3}. The crop response factors (Ky) under the FFI and AFI treatments were 0.67 and 0.92 respectively. This means that the relative reduction in grain yields under deficit irrigation was lower than the relative reduction in evapotranspiration. These values indicated that the eggplant was not sensitive to water deficiency and was more adapted to the irrigation program under water deficit conditions. Based on these results, it recommended growing eggplant under deficit irrigation without considerable loss in marketable yield. The yield response factor (Ky) was determined as 0.60 by Ertek et al. (8) and as 0.81 by Şenyiğitet al. (30).On the contrary, Lovelli et al. (20) obtained a Ky value greater than 1, pointing that eggplant has some sensitivity to water stress. When the supply of water is restricted, irrigation can be applied through treatments like alternate furrows. This system saves quite a considerable amount of water and is very useful and central in areas of water shortage (21).

Effect of cutback irrigation on irrigation performance

Fig.6 presents the effect of cutback irrigation on irrigation performance in terms of irrigation efficiency and distribution efficiency or uniformity (C_u) during a separate experiment that was implemented during the summer season of 2018. The furrows were 70 m in length and were not block ended. It is commendable to mention that the flow rate was reduced to half the original flow rate when water travelled 50% of the total length. The cutback treatment leads to a slight increase in Ed by about 2% compared to the conventional furrow irrigation. On the other hand, this treatment resulted in about 10% increase in irrigation application efficiency.

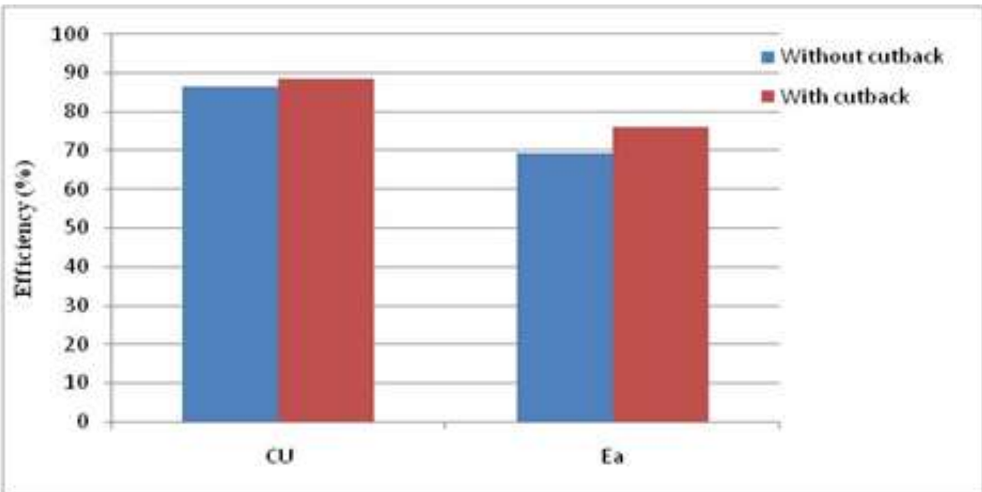

Fig6. Irrigation performance as influenced by cutback treatment

Effect of surge flow on advance time

Table 3 displays the average advance time in minutes after measuring the rate of advance of water during 12 successive irrigations in separate experiments implemented during the summer seasons of 2017 and 2018 in presence of eggplant. The lengths of the furrows were 30 and 70 m during the first and second season's respectively. As can be seen in Table 3 there was a steady increase in advance time with an increase in cycle ratio from 1/3 to 1.0, the implies that among the treatments, the surge flow with a cycle ratio of 1/3 advanced faster than the others. It was also observed that the advance time taken to complete the full advance distance by the surge flow with a cycle ratio of 1/3 was about 69% and 55% less than the respective continuous flow treatment with furrow lengths of 30 and 70 m respectively. Similarly, the surge flow with a cycle ratio of 2/3 reached the end of the furrow by 42% and 33% less time than the continuous flow treatment respectively. The obtained results are due to a net reduction in the infiltration rate under surge flow. These results are in parallel with the findings of Kanber et al. (19) who noted that surge flow with the small cycle ratio has the greatest effect on reducing the advance time. Additionally, it was noticed that the surge flow with a cycle ratio of 1/3 recorded the highest advance rate (2.78 m min^{-1}) when the furrow length was 30 m. By contrast, the lowest advance rate (0.30 m.min^{-1}) was recorded under the continuous flow (cycle ratio= 1) when the furrow length was 70 m.

Effect of surge flow on furrow irrigation performance

Fig.7 shows the effect of different cycle ratios on irrigation performance in terms of application and distribution efficiencies respectively. As can be seen in Figs. 7 and, the cycle ratio of 2/3 offered the highest value for Ea and Ed respectively, followed by the cycle ratio of 1/3. This means that surge flow led to higher irrigation efficiency and more uniform water distribution efficiency than those under conventional irrigation. It is also apparent from the presented results the effectiveness of surge flow on increasing irrigation performance was more pronounced in furrows with a length of 70 m than with a furrow in 30 m. The higher advance rate under surge flow reduced the difference in opportunity time between the upper and the lower parts of the furrows, resulting in higher irrigation efficiency a more uniform water distribution along the irrigation run. The obtained results from the current study confirmed the findings of Issaka (14) and Mustafa (26) who observed that the surge technique gave a better irrigation performance in terms of application and distribution efficiencies compared with other irrigation techniques. The ANOVA test also revealed that the irrigation performance in terms of Ea and Ed differed significantly ($P \leq 0.05$) from those under continuous flow.

Table3. Time required for water to reach the lower ends of the furrows during surge flow under different cycle ratios

Irrigation Event #	Cycle ratio	Advance time (min)		Travel speed (m.min^{-1})	
		30 m	70 m	30 m	70 m
	1/3	6.0	38.0	5.0	1.8
1	2/3	10.0	59.0	3.0	1.2
	1	22.2	106.05	1.4	0.7
	1/3	6.4	34.0	4.7	2.1
2	2/3	11.2	52.4	2.7	1.3
	1	22.35	99.59	1.3	0.7
	1/3	8.4	37.2	3.6	1.9
3	2/3	17.2	60.4	1.7	1.2
	1	26.26	102.22	1.1	0.7
	1/3	8.8	46.0	3.4	1.5
4	2/3	16.4	66.0	1.8	1.1
	1	35.36	103.08	0.8	0.7
	1/3	8.4	66.0	3.6	1.1
5	2/3	21.2	91.8	1.4	0.8
	1	37.6	101.83	0.8	0.7
	1/3	6.0	49.2	5.0	1.4
6	2/3	16.0	66.4	1.9	1.1
	1	36.06	100.06	0.8	0.7
	1/3	16.4	42.0	1.8	1.7
7	2/3	32.0	64.0	0.9	1.1
	1	39.14	104.48	0.8	0.7
	1/3	16.4	54.4	1.8	1.3
8	2/3	20.8	64.8	1.4	1.1
	1	38.11	106.42	0.8	0.7
	1/3	14.0	48.8	2.1	1.4
9	2/3	28.8	83.2	1.0	0.8
	1	39.3	104.24	0.8	0.7
	1/3	10.0	39.2	3.0	1.8
10	2/3	20.4	58.0	1.5	1.2
	1	38.34	92.33	0.8	0.8
	1/3	17.2	34.0	1.7	2.1
11	2/3	26.0	61.2	1.2	1.1
	1	38.39	85.3	0.8	0.8
	1/3	11.6	38.2	2.6	1.8
12	2/3	20.8	61.2	1.4	1.1
	1	38.38	75.18	0.8	0.9

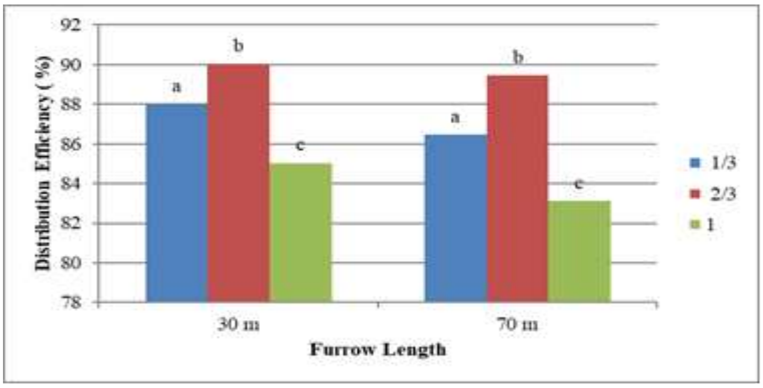

Fig7. Irrigation performance affected by cycle ratio on distribution efficiency

Effect of surge flow on fruit yield and water use efficiency of eggplant

As can be observed in Fig.8 the highest yield (57.91 t/ha) was observed from the surge flow with a cycle ratio of 2/3 treatment and the least yield (35.37 t/ha) from the continuous flow during the field experiment where the furrow length was 30m. Similarly, the surge flow with the cycle ratio of 2/3 and the continuous flow offered the highest and lowest yield (47.11 versus 28.09 t/ha) when the furrow length was 70 m. Irrespective of cycle ratio, a substantial reduction in fruit yield was observed as the furrow length increased from 30 to 70 m. From a field study by Gudissa (9), it was concluded that the surge system is promising technology for pepper production in areas with minimal water use. The analysis of variance showed that the eggplant fruit yield under the two sub experiments were high significantly affected by cycle ratio.

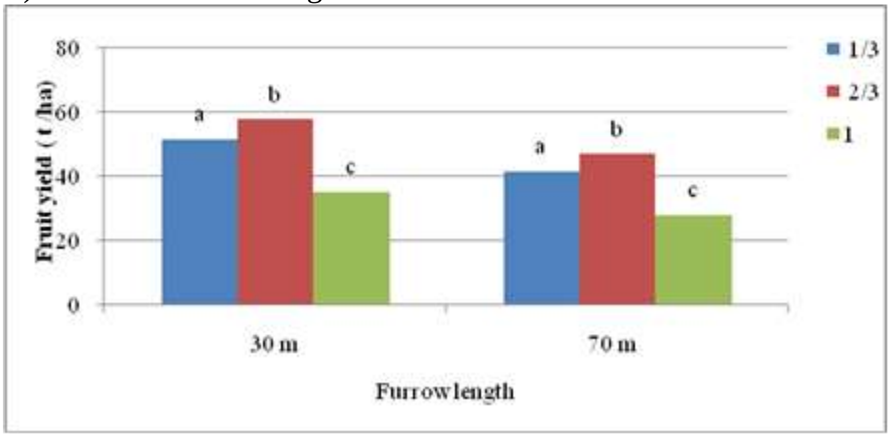

Fig8. Eggplant fruit yield as affected by cycle ratio during the surge flow experiment

The highest water use efficiency under surge flow with a cycle ratio of 2/3 was concomitant with the highest fruit yield under this treatment during the two sub-experiments (Table 4). Ismail et al. (12) indicated that under cropped condition surge irrigation can improve irrigation performance and water use efficiency. The higher water efficiency under surge irrigation compared with the continuous flow is due to reduced deep percolation and enhanced storage efficiency and distribution uniformity. Like fruit yield, the water use efficiency was high significantly affected by surge irrigation under both sub experiments. The Dunnett's test revealed that this parameter differed high significantly from that under control for both furrow lengths (Table 4). Additionally, it can be noticed from Table 4 that water use efficiency was about 31.74% and 63.8% more than the respective continuous flow treatment when the cycle ratios were 1/3 and 2/3 respectively in the sub experiment with a furrow length of 30 m. On the other hand, the percent of increase in water use efficiency under cycle ratios of 1/3 and 2/3were 48.69 and 67.67% in the sub experiment with a furrow length of 70 m. Overall, the applied treatments can be ranked according to the degree of their effectiveness in term of irrigation performance, eggplant yield and water use efficiency as follows:

Surge flow> Fixed furrow irrigation > Alternate furrow irrigation > Cutback > continuous flow.

Table4. Percent of increase in water use efficiency of eggplant due to different cycle ratios

Furrow length (m)	Cycle ratio	Average water use efficiency (kgm^{-3})	Absolute difference|Ti-T3|	Percent of increase with respect to control=[100 |Ti-T3|]/T3]
30	1/3	12.41	3.94	31.74
	2/3	13.87	5.40	63.80
	1	8.47		
	Dunnett D (0.05)		1.06	
70	1/3	9.98	3.27	48.69
	2/3	11.25	4.54	67.67
	1	6.71		
	Dunnett D (0.05)		1.12	

It can be concluded from the obtained results that surge irrigation is the most effective method for enhancing irrigation performance and water productivity in the cracked soil, followed by a fixed alternate irrigation method. Furthermore, reducing both furrow length and percent of depletion of available water and using-V-shaped section were in favor of improving irrigation performance and water productivity.

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