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Impacts of changing flow rate and furrow length on hydraulic performance of furrow irrigation system under clay soil

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ABSTRACT

Aim: The aim of this study was to investigate the impacts of varying furrow continuous flow rate and length of furrow on the performance parameters of furrow irrigation**.**

Materials and Methods: It was directed to qualify the degree of the relations by conducting a set of field trials to test and evaluate the hydraulic performance (Application "Ea", Distribution "Ed", Storage efficiencies "Es", Deep Percolation "DP" and Tail Water Losses "TWL") for three furrow lengths (120.140, 160 m), and three flow rates (2.7, 2, 1.5 L/s) using factorial design with three replicates (first, second and third irrigation).

Results: The statistical analysis of impacts of changing flow rate and furrow length on hydraulic performance indices indicated that the effect of furrow length was not statistically significant while it is highly significant for flow rate for all performance indicators. These implied that the designer has much freedom to select the furrow length that fit with field layout, but obliged to use non-erosive high flow rate. The Interaction between length and flow rate on was significant ($P<0.05$) and 120 m furrow length and 1.5 l/s flow rate gave highest Ea of 59.29% while Interaction of 120 m furrow length on 2.7 l/s flow rate resulted in improved Ed (87.1%) and the minimum Ea of 39% resulted from (160 m at 2.7 l/s) under clay soil..

Conclusion: The field data from three irrigations on changes of furrow cross-sectional areas concluded that the net rates of soil loss in the upper part of the furrow (head) were higher than the average net rate for the whole furrow. The soil loss was directly related to the in flow rate and inversely related to furrow length.

Keywords: Application efficiency, Furrow irrigation, Furrow length, Furrow Performances, Flow rate.

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Introduction

Surface irrigation methods are extensively used throughout the world. Unfortunately, the methods often have lower application efficiencies and distribution uniformities than pressurized systems. High runoff and deep percolation losses are cited as the main problems. Low initial investment and farmers' preferences undoubtedly encourage the use of surface irrigation methods. While, limited energy resources and labor availability restrict the use of sprinkler and trickle systems. High efficiencies can be attained if the design parameters of surface irrigation system (field length and flow rate, infiltration characteristics and field slope) are properly designed, and if the operating and management parameters (application depth, cut off time and frequency) are properly maintained. Efficiency in excess of 90% can be achieved in some cases by careful preparation of soil, proper engineering design and good operation and management (Latif and Ittfaq, 1998 and Torres et al., 2010).

Furrows are small charnels having a continuous nearly uniform slope and usually perpendicular to the field supply canal. Furrow irrigation is one of the most widely used surface irrigation technologies worldwide. Furrow Irrigation can be used for almost all kind of crops and best suited for farmers with small scale holdings. Furrow irrigation requires quite a lot of labour input but practically low investments. Furrow layout can be used on different types of soils slopes and farm shapes. Improved efficiency in irrigation system design can help reduce the amount of irrigation water applied there by reducing water-logging and salinity problems while at the same time maintaining crop water needs (Walker and Skogerboe, 1987). Water under furrow irrigation can be used more efficiently compared to basin and border irrigation systems by easily control of inflow rate and by implementing cutback or surge techniques (Elliott and Walker, 1982). Improving the performance of a furrow irrigation system requires not only achieving high distribution uniformity but other indicators to measure of irrigation performance (Ea,Es,DP, and TWL) are important (Elliott and Walker, 1982). The efficiency of furrow irrigation is reported worldwide about 60 %, which means that 40 % of the given water is lost due to runoff and percolation (Torres et al., 2010). Techniques be used to increase furrow irrigation efficiency includes selection of proper design variables (inflow rate, length of run, slope, application depth), maintaining good operating parameters (using tail bunds, cutoff time, cutback and surge flow) (Okereke et al., 2005 and Issaka et al., 2015).

Many investigators studied the problem of selecting furrow inflow rate and furrow length via assessing their impacts on Ea only without considering other hydraulic performance parameters. One of these investigators, Mekonen (2006) who tested three flow rates (0.3, 0.4 and 0.5 lit/s) and three furrow length (24, 35 and 50 m) in split plot design at Batu Degaga and found that average Ea of 28.9, 33.6 and 40.46% for furrow lengths of 24, 35 and 50 m, respectively. For flow rates, the average values of Ea obtained is 32.9, 32.8 and 36.9% for the flow rates of 0.3, 0.4 and 0.5 lit/s, respectively. Another study, is conducted by Eshetu (2007) at Yilmana Densaworeda, West Gojam Zone of Ethiopia, to evaluate effects of flow rates (0.4, 0.6, 0.8 lit/s) and furrow lengths (10, 25 and 40 m) on application efficiency found higher application efficiencies on longest furrow (40 m) as well as lowest flow rate (0.4 lit/s).

Pereira and Trout, 1999 indicated from a study on furrow irrigation erosion and management that the soil loss was directly related to the inflow rate and inversely related to furrow length. Raine and Bakker (2005) identified a range of methods to improve water application efficiencies in the sugar industry including the use of appropriate furrow lengths, irrigation cut off times and water application rates. Eldeiry et al (2005) applied a volume balance model to simulate water flow in the furrow system, and compared the results with field measurements on clay soil. The study shows that the length of the furrow and its inlet inflow are the main factors affecting application efficiency and to obtain high application efficiencies, furrow inflow rates must increase with longer furrow lengths.

Yigezu et al (2014) conducted field study to assess the effect of furrow length (16m, 32m, and 48m) and flow rate (0.52l/s, 0.79l/s, and 1.05l/s) on irrigation performance and maize yield. They reported that the effect of furrow length and their interaction with flow rate on yield were not significant (P=0.01) but the flow rate has significant effect on yield (P<0.01), and the irrigation performance indicators (Ea, DPR, SRR, Es, and Ed) were significantly affected by both furrow length and flow rate. They concluded that open-ended short furrows were the major source of water loss through surface runoff that has resulted lower adequacy of water in the crop root zone.

Assefa et al (2017) evaluated effects of slope, furrow length (100, 150 and 200 m) and flow rate (4, 5 and 6 L/s) on irrigation performances, and cane and sugar yield at Metehara sugar estate. They found that the analysis of performance indices shows that the effect of slope was not statistically significant except Ed, but furrow length and flow rate were highly significant on all performance indicators. All indices except deep percolation ratio and storage efficiency have shown an increasing trend as flow rate increases. The interaction of 200 m furrow length of and 6 lit/s flow rate gave better Ed and cane yield and slope of 0.08% was recommended for Metehara Sugarcane Plantation.

Optimal furrow length and irrigation cutoff can be determined, as related to soil infiltration characteristics, by the time ratio (ratio between the time required for infiltration of total amount of water required for root zone and the time when the advancing water front reaches the end of the run) to achieve maximum application efficiency (Assefa et al., 2017 and Kannan and Abate, 2015). It is theoretically assumed that the optimum furrow length is reached when the maximum Ea can be achieved at certain applied irrigation depth. However, the maximum efficiency itself is function to inflow rate and it is also affected by the infiltration and advance functions (Elliott and Walker, 1982). Assefa et al, (2017) stated that furrow Ea and Ed depend on furrow parameters including: inflow rate, soil texture, field slope, soil infiltration, plant coverage, roughness coefficient, field shape, and irrigation management. It was reported that it is essential to understand the role and inter-dependence of these factors, for they determine the prescribed amount of water to apply and ensure uniform application down the full furrow length.

Uniform flow in furrows depends on soil infiltration properties and flow rate. For this reason, the quarter time rule is very often used in to judge the furrow irrigation application efficiency. The quarter time rule is the time that water reaches to end of furrow has to be equal ¼ of time the water would give to furrow for depletion. If the time over than ¼ of applying depletion time, it imposes serious problems on fields that allow water high deep percolation from soil surface to deeper soil profiles and this is meaning of low application efficiency (Kara 2008). This quarter time rule is related to the interaction of flow rate with furrow length (Okereke et al., 2005 and Assefa et al., 2017).

Holzapfel et al (2010) conducted a study to analyze the relationship between the variables of furrow irrigation and the irrigation performance parameters, crop yield, and deep percolation as a basis for furrow irrigation design and management. (Ea), requirement efficiency (Er), (Ed), and furrow irrigation management, operation, and design variables (inflow discharge, furrow length, and irrigation cutoff time) were correlated. The relationship between performance irrigation parameters and relative yield was also examined. Study results indicate that increasing the length of the furrow reduces Er, and Ea values, while, an increase in inflow discharge and cutoff time increases efficiency. They recommended Ea parameters for the design, management, and operation of furrow irrigation systems, in order to establish good irrigation practices.

Askari and Shayannezhad (2015) studied furrow design variables (furrow length, flow rate and cut-off time) through optimization based on minimizing the total irrigation cost and maximizing the application efficiency of irrigation. The objective function has been formed based on costs of the water, worker and head ditch and furrow digging. According them increasing or decreasing the furrow length, decrease the irrigation efficiency and increase its cost. Similarly, the slope of cost and irrigation efficiency relative to inflow rate (0.0498 3/min), increasing or decreasing the inflow rate, irrigation cost increase and irrigation efficiency decreases.

As given above the individual impact of furrow inflow rate and furrow length on furrow application efficiency is studied by many investigators but they did not give much consideration to the interaction effect of these two design parameters nor did they show their statistical sensitivity. Strelkoff et al (2020) stated that field properties have a profound effect on the performance of surface irrigation systems. They reported that "reasonable estimates of these parameters are crucial to good management and design. Yet, quantitative evaluation, to the necessary accuracy, for predictions of performance and concomitant recommendations for physical design or system operation is elusive". They added that the difficulty in selecting appropriate values, with their spatial variation and changes with time (both in the course of a single irrigation and over a season) accounts in part for the poor reputation of surface systems for non-uniform application of water and excessive deep percolation and runoff.

The objective of this study was to knowledge hydraulic performance of furrow irrigation using field data with clay soil. The aim is to recommend optimum flow rate, furrow length and advance time under open-end furrow irrigation inn flat fields with clay soil and constant irrigation depth.

Materials and Methods

Site Description: The study was conducted at the Faculty of Agricultural Technology and Fish Sciences, Al Neelain University, which is found about 44 km south of Khartoum city, on the eastern bank of the White Nile, (15°23′ N Latitude, 32°54′ E Longitude and altitude of 384 m), with mean annual rainfall of 121 mm and classified as semi-desert /arid climatic region. The mean annual maximum and minimum temperature was 29.9 °C and 26.3°C respectively. The mean annual relative humidity ranges between 26-21% (Jan to Feb), 15-16% (March to June) and 14-48% (July to Sep). The dominant soil types in the area are clay textured soil.

Experimental Details: A field measuring area of 160 m× 21 m (3360 m2) was selected for experimentation. Land preparation was made using chisel plow, leveling with scraper and furrows made by a ditcher. The area was divided into three blocks (representing the lengths of furrow: 120 m, 140 m, 160 m) of 160x 7 m, and each block consist of 5 furrows with furrows spaced at 1.4 m ,the middle three furrows were used for monitoring irrigation events and the outer furrows used as a buffer furrows. The flow applied to each furrows was measured with a 2-inch-Parshall flume situated at the upstream head of each furrow. A v-notch weir was positioned in each furrow at its downstream end to monitor the rate of tail water run-off. The depth of each irrigation was kept as 65 mm.

Experimental Design: The experiments treatments include two factors namely furrow length (as main plot) and flow rate (as sub-plot) with three replications. The levels of treatments include three rates for each factor. The furrow length was 120m, 140m, and 160m. The flow rates were 2.7L/s,2l/s,1.5l/s. The data were analyzed with ANOVA technique using Statistix 8.0 model to determine which means were significantly different, and LSD multiple comparison tests were used.

Field Measurements: Soil moisture samples were taken to a depth of 90 cm in 25 cm increments to determine soil type. Particle size analysis of the Composite samples was performed in the laboratory using the soil hydrometer method. The soil type was classified using the U.S. Soil Survey textural triangle and was found to be clay. Field capacity, permanent wilting point and bulk density was determined according to Michael (1978) and Vomocil (1957). Soil analysis data were recorded (Table 1).

Soil moisture content sample was taken For each treatments at 24 hr before irrigation and two day after irrigation at four locations along the furrows from two layers (0-20 and 20-40 cm) using gravimetric method. To evaluate irrigation performance of individual furrows the standardize procedures developed by the ASAE Surface Irrigation Committee was adopted (ASABE Standards, 2006). Furrow cross sections were determined using profile-meter before and after irrigation at three sites located at (furrow top, middle and tail section), and furrow water depth and width data was collected at each Station on along the furrows to determine water storage volume during advance phase(Walker and Skogerboe, 1987). Furrow flow rates were measured using three- inches Par shall flumes placed at the upstream of the furrows. Flow rates were initially measured every 3 min until it became stable. After stabilization, measurements were taken every 10 min. The flow rates were determined by the formula Skogerboe et al., (1965).

$$Q = 0.676H_a^{1.55} \ldots\ldots\ldots\ (1)$$

Where: Q = free flow rate (ft3/s); Ha= depth of flow in a Parshall flume located two-thirds of the length of the converging entrance section upstream from the throat crest, ft.

Measurement of advance and recession times: It was taken in ten stations along the furrows for each irrigated, combination. Stakes were driven into the soil in each station along the furrows before irrigation events. Advance times (ta) were recorded at the time when water reaches each stakes while recession times (tr) were recorded at times when water infiltrated or disappeared from the furrow bed at observation stations (Walker and Skogerboe, 1987).

Application efficiency: Okereke et al., (2005) defined water application efficiency as the ratio of the average low quarter depth of irrigation water infiltrated and stored in the root zone to the total depth of water delivered to the field thus:

$$E_a = 100 \times \frac{Z_{reqL}}{Q_o t_{co}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

Where: Ea= water application efficiency (%); Zreq = required infiltration volume per unit length (m3/m); L= furrow length (m); Qo= field inflow (m3/min); andtco= time cut off (min).

Deep Percolation Losses: The loss of water through drainage beyond the root zone is reflected in the deep percolation losses, DPL, and defined (Walker and Skogerboe, 1987) as:

$$DPL = 100 \times \frac{\text{Volume of deep percolation}}{\text{Volume of water applied to the field}} \ldots\ldots\ldots\ldots\ldots\ldots\ (3)$$

Tail Water Losses: Losses of irrigation water from the irrigation system through surface run-off from the end of the field are indicated in the tail water losses, and defined (Walker and Skogerboe, 1987) as:

$$TWL = 100 \times \frac{\text{Volume of surface runoff}}{\text{Volume of water applied to the field}} \ \ldots (4)$$

Table 1: Soil Characteristics of the studied fields

Soil depth Cm	Black density g/m³	Flied capacity %	Wilting Point %	Sand %	Slit %	Clay %	Textural Class	PH	EC ds/m
0.0-25	1.43	28.4	17.7	40.4	5.90	53.7	clay	8.0	3.72
25-50	1.46	27.0	16.9	33.4	13.4	53.2	clay	8.1	4.89
50-75	1.47	25.1	15.8	43.5	8.70	47.8	clay	8.1	5
75-90	1.50	24.4	15.5	47.3	4.30	48.4	clay	8.2	5.3
Average	1.47	26.23	16.48	41.15	8.07	50.78	clay	8.1	4.73

Distribution efficiency: Eisenhauer et al. (2021) defined the Christiansen uniformity coefficient (CU) as important index to indicate application uniformity and CU is determined as:

$$\mathrm{CU} = 100\left(1 - \sum_{i=1}^{n} \frac{|d_i - d_z|}{n d_z}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Where: di = depth of observation i, dz = mean depth infiltrated for all observations, and n = number of observations. The calculated value is multiplied by 100 to provide an index value between 0 and 100. Note that $\sum_{i=1}^{n} \frac{|d_i - d_z|}{n}$ is the average deviation from the mean.

Storage Efficiency: This is also referred to as the water requirement efficiency and is defined (Walker and Skogerboe, 1987) as:

$$E_s = 100 \times \frac{\text{Volume of water added to the root zone}}{\text{Potential soil moisture storage volume}} \ldots\ldots \quad (6)$$

Results and Discussion

Advance and recession time: The average advance and recession time for continuous flow were recorded (Fig. 1-3), during 1st, 2nd and 3rd irrigation. The average advance time for furrow length of 120 m was 69.7, 75.9 and 79.9 min at 2.7, 2, and 1.5 l/s flow rates, respectively. Results showed that the flow rate of 2.7 l/s advanced faster than the waterfront advance rate (1.7 min/m) than the 2 and 1.5 l/s flow rates. This may be due to reducing the amount of percolated water in the furrow head (El Gindy et al, 2001). This implied that under discharge rates will have a greater contribution to the variability in advance time than furrow length. It can be observed that the advance time taken to complete the full advance distance by 2.7 l/s was about 8.9% less time than the flow rate of 2 l/s. Similarly, 2.7 l/s reached the end of the furrow by 14.6% less time than the flow rate of 1.5 l/s. On the other hand, 2 l/s arrived at the tail end of the furrow with 5.3% less time than the flow rate of 1.5 l/s. The coefficient of variation of a given furrow flow rate (2.7, 2, 1.5 l/s) across all irrigation stations within the site was high. It was from 59.7, 59.1 and 59.4 % in first irrigation and 60.9, 57.7, 53.7 % in second irrigation and 60.5,57 and 54.1in third irrigation. The average recession time for furrow length of 120 m was 185.8, 2177 and 260 min at 2.7, 2, and 1.5 l/sec flow rates, respectively. These results were in agreement with the results of Guirguis et al. (2013) found that the value of advance time decreased as inflow rate increase, this was due to fast movement of water in horizontal direction than infiltrate it in vertical direction. Also, the recession time increased as inflow rate increased, this can be explained that increasing inflow rate, water infiltrated into soil takes more time to disappear.

Whereas, in the 140 m furrow length it was mean advance time from 81.7, 92.1 and 106 min corresponding to 2.7, 2 and 1.5 l/s flow rates, respectively. Results showed that the flow rate of 2.7 l/s advanced faster than the waterfront advance rate (1.7 min/m) than the 2 and 1.5 l/s flow rates. It can be observed that the advance time taken to complete the full advance distance by 2.7 l/s was about 12.7% less time than the flow rate of 2 l/s. Similarly, 2.7 l/s reached the end of the furrow by 30.6% less time than the flow rate of 1.5 l/s. It was observed that the 2 l/s flow rate arrived at the tail end of the furrow with 15.9% less time than the flow rate of 1.5 l/s. The coefficient of variation of a given furrow flow rate (2.7, 2, 1.5 l/s) across all irrigation stations within the site was high. It was from 59.2, 59.1 and 55.8 % in first irrigation and 59.9, 58.9, 59.8 % in second irrigation and 59.2, 58.3 and 59.6in third irrigation. The average recession time for furrow length of 140 m was 209.3, 248.3 and 307.3min at 2.7, 2 and 1.5 l/sec flow rates. These results were in agreement with the results of Guirguis et al. (2013).

Regarding, the 160 m furrow length it was mean advance time from 82.8, 94.5 and 113.7 min corresponding to 2.7, 2 and 1.5 l/s flow rates, respectively. Results showed that the flow rate of 2.7 l/s advanced faster than the waterfront advance rate (1.9 min/m) than the 2 and 1.5 l/s flow rates. It can be observed that the advance time taken to complete the full advance distance by 2.7 l/s was about 18.1% less time than the flow rate of 2 l/s. Similarly, 2.7 l/s reached the end of the furrow by 20.3% less time than the flow rate of 1.5 l/s. The 2 l/s flow rate arrived at the tail end of the furrow with 20.3% less time than the flow rate of 1.5 l/s. The coefficient of variation of a given furrow flow rate (2.7, 2, 1.5 l/s) across all irrigation stations within the site was high. It was from 62.9, 63.1 and 62.8 % in first irrigation and 64.2, 60.2and 65 % in second irrigation and 64, 60.1and 64.6 % in third irrigation. The average recession time for furrow length of 160 m was 221.7, 265.8 and 334.5 min at 2.7, 2 and 1.5 l/sec flow rates. These results were in agreement with the results of Guirguis et al. (2013).

The empirical relations were obtained for both advance and recession times for the relationship with distance (Table 3) as best fit power equations. That gave higher values of coefficient of determination (R2) both for advance and recession time times for all treatments as recorded (Table 2 and Table 3) respectively.

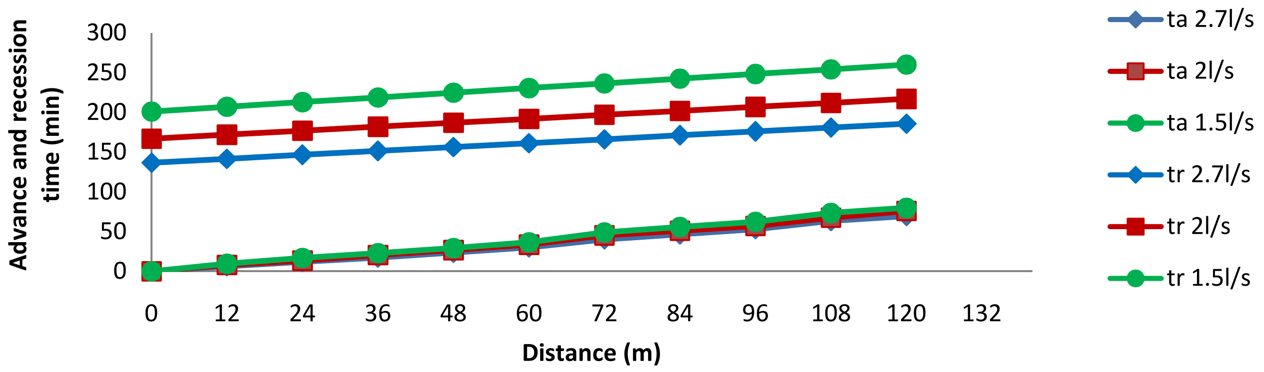


Fig. 1: Average advance and recession curves for furrow irrigation system for length 120 m

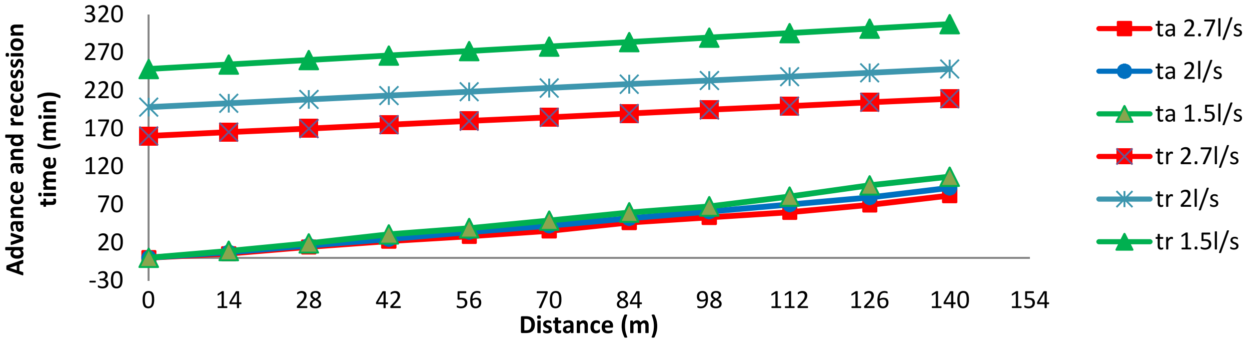


Fig. 2 : Average advance and recession curves for furrow irrigation system for length 140 m

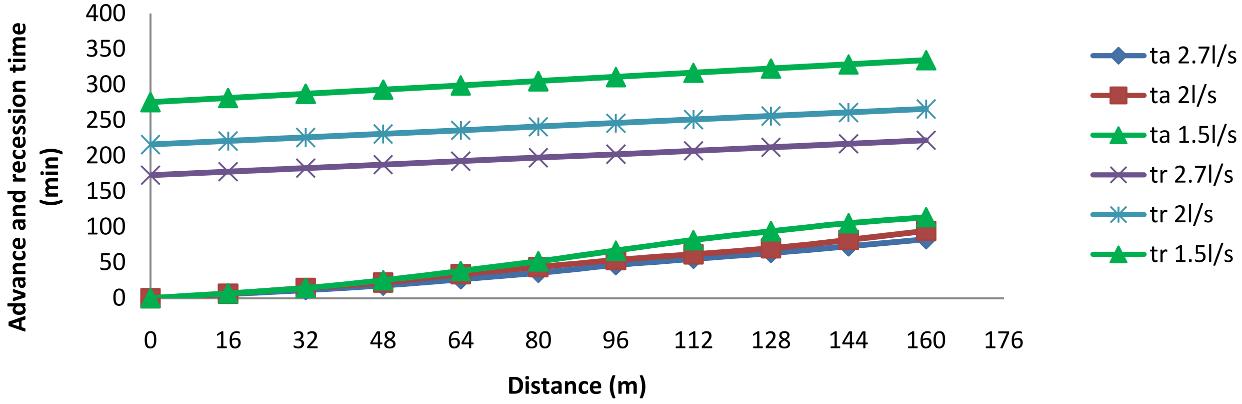


Fig. 3: Average advance and recession curves for furrow irrigation system for length 160 m

Table 2: The developed relations for prediction of time advance.

Inflow rate L/s	1st irrigation	2nd irrigation	3rd irrigation
Furrow length (120 m)			
2.7	$t_a = 0.411x^{1.053}$ $R^2 = 0.993$	$t_a = 0.432x^{1.062}$ $R^2 = 0.994$	$t_a = 0.426x^{1.058}$ $R^2 = 0.995$
2	$t_a = 0.413x^{1.088}$ $R^2 = 0.997$	$t_a = 0.702x^{0.967}$ $R^2 = 0.986$	$t_a = 0.689x^{0.963}$ $R^2 = 0.988$
1.5	$t_a = 0.551x^{1.042}$ $R^2 = 0.991$	$t_a = 1.041x^{0.895}$ $R^2 = 0.991$	$t_a = 0.98x^{0.902}$ $R^2 = 0.991$
Furrow length (140 m)			
2.7	$t_a = 0.417x^{1.069}$ $R^2 = 0.997$	$t_a = 0.273x^{1.15}$ $R^2 = 0.993$	$t_a = 0.274x^{1.143}$ $R^2 = 0.993$
2	$t_a = 0.467x^{1.079}$ $R^2 = 0.999$	$t_a = 0.369x^{1.111}$ $R^2 = 0.999$	$t_a = 0.368x^{1.104}$ $R^2 = 0.999$
1.5	$t_a = 0.773x^{0.994}$ $R^2 = 0.997$	$t_a = 0.438x^{1.11}$ $R^2 = 0.998$	$t_a = 0.431x^{1.1056}$ $R^2 = 0.998$
Furrow length (160 m)			
2.7	$t_a = 0.175x^{1.188}$ $R^2 = 0.998$	$t_a = 0.2x^{1.199}$ $R^2 = 0.995$	$t_a = 0.1991x^{1.195}$ $R^2 = 0.996$
2	$t_a = 0.209x^{1.193}$ $R^2 = 0.995$	$t_a = 0.258x^{1.173}$ $R^2 = 0.998$	$t_a = 0.256x^{1.168}$ $R^2 = 0.998$
1.5	$t_a = 0.211x^{1.241}$ $R^2 = 0.998$	$t_a = 0.182x^{1.291}$ $R^2 = 0.996$	$t_a = 0.184x^{1.282}$ $R^2 = 0.996$

Table 3: Empirical relations developed for prediction of time of recession.

Inflow rate L/s	1st irrigation	2nd irrigation	3rd irrigation
Furrow length (120 m)			
2.7	$t_r = 98.168x^{0.122}$ $R^2 = 0.926$	$t_r = 104.17x^{0.117}$ $R^2 = 0.925$	$t_r = 101.39x^{0.119}$ $R^2 = 0.925$
2	$t_r = 128.85x^{0.102}$ $R^2 = 0.923$	$t_r = 130.73x^{0.101}$ $R^2 = 0.923$	$t_r = 126.97x^{0.104}$ $R^2 = 0.923$
1.5	$t_r = 158.12x^{0.01}$ $R^2 = 0.922$	$t_r = 155.76x^{0.101}$ $R^2 = 0.922$	$t_r = 153.87x^{0.102}$ $R^2 = 0.923$
Furrow length (140 m)			
2.7	$t_r = 124.24x^{0.102}$ $R^2 = 0.923$	$t_r = 121.62x^{0.104}$ $R^2 = 0.923$	$t_r = 117.69x^{0.106}$ $R^2 = 0.923$
2	$t_r = 163.37x^{0.085}$ $R^2 = 0.92$	$t_r = 155.37x^{0.088}$ $R^2 = 0.921$	$t_r = 150.61x^{0.091}$ $R^2 = 0.921$
1.5	$t_r = 198.98x^{0.083}$ $R^2 = 0.92$	$t_r = 200.03x^{0.083}$ $R^2 = 0.92$	$t_r = 195.73x^{0.084}$ $R^2 = 0.92$
Furrow length (160 m)			
2.7	$t_r = 119.94x^{0.104}$ $R^2 = 0.923$	$t_r = 137.84x^{0.094}$ $R^2 = 0.92$	$t_r = 135.49x^{0.095}$ $R^2 = 0.922$
2	$t_r = 167.43x^{0.083}$ $R^2 = 0.92$	$t_r = 174.59x^{0.080}$ $R^2 = 0.92$	$t_r = 171.82x^{0.081}$ $R^2 = 0.92$
1.5	$t_r = 214.86x^{0.078}$ $R^2 = 0.92$	$t_r = 228.11x^{0.075}$ $R^2 = 0.92$	$t_r = 223.3x^{0.076}$ $R^2 = 0.92$

Furrow evaluation: The free-drainage furrow irrigation system can be optimized by choosing the optimal value of the inflow rate and cutoff time to achieve the highest application efficiency. The application efficiency, distribution uniformity, storage efficiency, runoff ratio and the deep percolation ratio were generally considered the critical indices of irrigation performance which can be used for design and management of free-drainage furrow irrigation systems (Elliott, and Walker, 1982). The results of the furrow evaluation are shown in table 4-6. The results of the cutoff time values for furrow length were 120 m in first irrigation of 133.5,167 and 203.5 min and the total volume of run-off were 11.6,8.7and 6.8 m3/furrow, respectively. While in the second irrigation for cutoff time, of 140,169 and 201 min, the total volume of run-off were 12.9, 9 and 7.4 m^3/furrow, respectively. In the third irrigation, there was a cutoff time of 137,165 and 199 min and the total volume of run-off were

13, 9.3 and 7.6 m3/furrow, respectively, for inflow rate at 2.7,2 and 1.5 L/s.

Similarly, for furrow length 140 m there was a cutoff time of 163.6, 205.6, 249.1 min and the total volume of run-off were 14.6, 8.4 and 8.1 m3/furrow respectively, in first irrigation and 160.8,197.2 and 250.2 min and the total volume of run-off were 15.4, 11.4 and 9.4 in second irrigation and 177.4, 216.4 and 276.8 min and the total volume of run-off were in the third irrigation 15.7,13.3 and 13.8 at 2.7,2 and 1.5 L/s.

For furrow length the 160 m in first irrigation the cutoff time values were 160.8, 211.and 268 min the second irrigation of 179.9, 219.3 and 281.8 min and 177.4, 216.4 and 276.8 min in the third irrigation. Also, of the total volume of run-off were 15, 12.4 and 9.8m3/furrow in the first irrigation, in the second irrigation of 17.8, 13.2 and 10.5 m3/furrow and third irrigation of 18.4.13.8 and 11.3 m3/furrow.

Application Efficiency (Ea): The results of this study for application efficiency were recorded (Table 7). The effect of furrow length on Ea was significant ($p<0.05$) there are no significant pair-wise differences among the means. The mean values of Ea were 52.44, 48.01 and 48.62 % for 120, 140 and 160 m furrow lengths. It was observed decrease from 52.44 to 48.01% when the furrow length increased from 120m to 140m. Effect of flow rate on Ea was significantly ($P<0.05$) there are two groups in which the means are not significantly different from one another with mean values of 56.18, 51.57 and 41.31 % for 1.5,2 and 2.7 lit/s flow rates, respectively. Ea has shown decreasing trend as flow rate increased. Effect of the Interaction length and flow rate on Ea was significant ($P<0.05$) there are five groups in which the means are not significantly different from one another. The highest value of Ea was 59.29% found from the treatment (120m at 1.5l/s) and the minimum Ea was 39.01% resulting from (160 m at 2.7 l/s). This was in agreement with the result of Elliott and Walker, (1982) and Eldeiry et al (2005) applied a volume balance model to simulate water flow in the furrow system, and compared the results with field measurements. The study showed that the length of the furrow and its inlet inflow were the main factors affecting application efficiency and to obtain high application efficiencies, furrow inflow rates must increase with longer furrow lengths. The obtained results were in line with Eldiery et al (2005) who show that in clay soils relatively high efficiencies can be obtained over a wide range of furrow lengths (100 to 300 m). They achieved, with a furrow inflow of 0.15 m 3 /min, efficiencies between 80% and 90% for lengths ranging from 115 to 330 m. It was stated that longer furrow lengths should be used under these conditions since it made the irrigation system more robust, and when using longer furrow lengths the irrigation system was less sensitive to variations in furrow inflow, furrow shape, field slope, and roughness. However, where longer furrow lengths were not possible, the application of water should be carefully controlled to maintain high efficiencies. Likewise, the results were in agreement with Yigezu et al (2014) that reported the irrigation performance indicators (Ea, DPR, SRR, Es, and DU) were significantly affected by both furrow length and flow rate. It was indicated that open-ended short furrows were the major source of water loss through surface runoff that has resulted lower adequacy of water in the crop root zone. The obtained results were supported by Assefa et al (2017) in their study for evaluation of effects of slope, furrow length (100, 150 and 200 m) and flow rate (4, 5 and 6 L/s) on irrigation performances, cane and sugar yield at Metehara sugar estate. It was found that distribution uniformity and uniformity coefficient; furrow length and flow rate were highly significant on all performance indicators. All indices except deep percolation ratio and storage efficiency have shown an increasing trend as flow rate increases. The interaction of 200 m furrow length of and 6 lit/s flow rate gave better distribution uniformity and cane yield with slope of 0.08% was recommended for Metehara Sugarcane Plantation.

Tail water ratio (TWR) and deep percolation ratio(DPR): The effect of furrow length on the TWR were significant ($P<0.05$) there are no significant pair wise differences among the means (Table 8, Fig 4,5) with mean indices of 47.15, 50.69 and 51.25% for furrow lengths of 120, 140 and 160 m respectively. It was showed an increasing trend with increasing furrow length. The effect of flow rate was significant ($P<0.05$) There were two groups in which the means were not significantly different from one another with mean indices of 43.016, 47.4 and 58.69% for flow rate 1.5,2 and 2.7 l/s respectively. The results of mean TWR were in increased trend with flow rate, this might be resulted because of the fastest flow rate has reduced the infiltration contact time and increased the tail water loss. The effect of the interaction length and flow rate on TWR was significant ($P<0.05$) There were three groups in which the means are not significantly different from one another. The maximum and minimum value of TWR was 60.99% (160m at 2.7 L/s) and 40.17 % obtained for 120 m furrow length by 1.5 L/s flow rate. The effect of furrow length DPR was significant at ($P<0.05$). There were no significant pair wise differences among the means with mean indices of 0.4, 1.31and 0.13%for furrow lengths 120,140 and 160 m respectively (Table 9). The results showed a decreasing trend of values DPR with increasing furrow length, except for the furrow length of 120 m. The effect of the flow rate on DPR was significant ($p<0.05$). There are no significant pair wise differences among the means with mean indices of 0.81, 1.03 and 0.0% for 1.5,2 and 2.7 L/s respectively. It was observed that the results of DPR decreased with increasing flow rate. The effect of the interaction length and flow rate on DPR was significant ($P<0.05$). There were no significant pair wise differences among the means. The maximum value of DPR was 2.43% found from the treatment (140m at 2l/s) and the minimum DRP was 0.0% resulting from (160 m at 1.5, 2 and 2.7 l/s). These results were in line with Yigezu et al (2014) for they concluded that open-ended short furrows were the major source of water loss through surface runoff that has resulted lower adequacy of water in the crop root zone.

Distribution efficiency (Ed): The analyses of variance effect of furrow length on distribution efficiency (Ed) were significant ($p<0.05$) while pair-wise no significant differences among the means. The mean Ed with respect to furrow length was 84.92, 84.66 and 86.53% for furrow length of 120, 140, and 160 m, respectively (Table 10, Fig. 4, 5). Regarding the effect of flow rate on distribution efficiency (Ed) was significant ($p<0.05$) There were two groups in which the means were not significantly different from one another. Mean Ed with of flow rate were 86.64, 83.79 and 85.68% for 2.7, 2, and 1.5 lit/s, respectively. It was observed that the (Ed) increased with increased flow rate, except for 1.5 l/s. Interaction effects of furrow length and flow rate on Ed was also highly significant ($p<0.05$) there are two groups in which the means are not significantly different from one another's. The maximum value of 87.10 % was obtained for, 120 m furrow length and 2.7 lit/s flow rate, whereas the minimum value of 81.20% was obtained for 2lit/s flow rate and 140 m furrow length. These results were not very different from the results mentioned by Gudeta (2020) effect of Furrow Irrigation Technical Parameters on Field Application Performances of Short Furrow and Yield of Onion Crop in Bako, Ethiopia. Found that distribution uniformity increases as the flow rate increased regardless of furrow lengths and decrease as the furrow length increase. However, these results were not very different from a similar study Assefa et al (2017) found that distribution uniformity and uniformity coefficient; furrow length and flow rate were highly significant on all performance indicators. The interaction of 200 m furrow length of and 6 lit/s flow rate gave better distribution uniformity and cane yield with slope of 0.08% was recommended for Metehara Sugarcane Plantation.

Table 4: Evaluation and performance of furrow system under field condition for first irrigation

Furrow length (m)	120			140			160		
Flow rate (L/s)	2.7	2	1.5	2.7	2	1.5	2.7	2	1.5
Cut-of time (min)	133.5	167	203.5	163.6	205.6	249.1	160.8	211.8	268
applied volume (m3)	21.6	20	18.3	26.5	24.7	22.4	26	25.4	24.1
The volume of water stored in roots zone (m3)	10	11.1	11.2	11.9	14.5	13.5	11	13	14.3
Tail water (m3)	11.6	8.7	6.8	14.6	8.4	8.1	15	12.4	9.8
Deep percolation (m3)	0	0.2	0.3	0	1.8	0.8	0	0	0
Application efficiency (%)	46.3	55.5	61.2	44.91	58.7	60.27	42.31	51.18	59.34
Tail water ratio	53.7	43.5	37.16	55.09	34.01	36.16	57.69	48.82	40.66
deep percolation ratio	0	1	1.64	0	7.29	3.57	0	0	0
Distribution efficiency (%)	90.2	82.9	85.7	83.8	83.7	89.5	83.7	87.6	80.7
Storage efficiency (%)	91.7	100	100	93.7	100	100	75.3	89	97.9

Table 5: Evaluation and performance of furrow system under field condition for second irrigation

Furrow length (m)	120			140			160		
Flow rate (L/s)	2.7	2	1.5	2.7	2	1.5	2.7	2	1.5
Cut-of time (min)	140	169	201	160.8	197.2	250.2	179.9	219.3	281.8
Applied volume (m3)	22.7	20.3	18.1	26	23.7	22.5	29.1	26.3	25.4
The volume of water stored in roots zone (m3)	9.8	11.1	10.7	10.6	12.3	12.9	11.3	13.1	14.9
Tail water (m3)	12.9	9	7.4	15.4	11.4	9.4	17.8	13.2	10.2
deep percolation (m3)	0	0.2	0	0	0	0.2	0	0	0.3
Application efficiency (%)	43.17	54.68	59.12	40.77	51.9	57.33	38.83	49.81	58.66
Tail water ratio	56.83	44.33	40.88	59.23	48.1	41.78	61.17	50.19	40.16
deep percolation ratio	0	0.99	0	0	0	0.89	0	0	1.18
Distribution efficiency (%)	84.3	84.6	82.8	88	80.3	85.1	89.7	85.8	92.4
Storage efficiency (%)	89.9	100	98.2	83.5	96.9	100	77.4	89.7	100

Table 6: Evaluation and performance of furrow system under field condition for third irrigation

Furrow length (m)	120	120	120	140	140	140	160	160	160
Flow rate (L/s)	1	2	3	1	2	3	1	2	3
Cut-of time (min)	137	165	199	156.6	192.2	245.7	177.4	216.4	276.8
Applied volume (m3)	22.2	19.8	17.9	25.4	23.1	22.1	28.7	26	24.9
The volume of water stored in roots zone (m3)	9.2	10.5	10.3	9.7	9.8	8.3	10.3	12.2	13.6
Tail water (m3)	13	9.3	7.6	15.7	13.3	13.8	18.4	13.8	11.3
Application efficiency (%)	41.44	53.03	57.54	38.19	42.42	37.56	35.89	46.92	54.62
Tail water ratio	58.56	46.97	42.46	61.81	57.58	62.44	64.11	53.08	45.38
Distribution efficiency (%)	86.8	83.2	83.8	87.1	79.6	84.8	86.2	86.4	86.3
Storage efficiency (%)	84.4	96.3	94.5	76.4	77.2	65.4	70.5	83.6	93.2

Table 7: Effect of flow rate, furrow length and the interaction between flow and length on application efficiency (%)

Furrow length (m)	**Flow rate (lit/s)**			Means
	2.7	2	1.5	
120	43.64CDE	54.40AB	59.29A	52.44A
140	41.29DE	51.01ABC	51.72ABC	48.01A
160	39.01E	49.30BCD	57.54AB	48.62A
Means	41.31B	51.57A	56.18A	
	L	**Q**	**L*Q**	
SE	2.55	2.55	4.42	
LSD(0.05)	5.36	5.36	9.28	

Table 8: Effect of flow rate, furrow length and the interaction between flow and length on Tail water ratio (%)

Furrow length (m)	**Flow rate (lit/s)**			Means
	2.7	**2**	**1.5**	
120	56.36AB	44.93C	40.17C	
140	58.71A	46.56BC	46.79BC	50.69A
160	60.99A	50.7ABC	42.07C	51.25A
Means	58.69A	47.4B	43.01B	47.15A
	L	Q	L*Q	
SE	3.08	3.08	5.33	
LSD (0.05)	6.47	6.47	11.20	

Table 9. Effect of flow rate, furrow length and the interaction between flow and length on deep Percolation Ratio (%)

Furrow length (m)	**Flow rate (lit/s)**			Means
	2.7	2	1.5	
120	0.00A	0.66A	0.55A	0.40A
140	0.00A	2.43A	1.49A	1.31A
160	0.00A	0.00A	0.39A	0.13A
Means	0.00A	1.03A	0.81A	
	L	**Q**	**L*Q**	
SE	0.75	0.75	1.30	
LSD(0.05)	**1.58**	**1.58**	2.73	

Table10: Effect of flow rate, furrow length and the interaction between flow and length on distribution efficiency (%)

Furrow length (m)	**Flow rate (lit/s)**			Means
	2.7	**2**	**1.5**	
120	87.10 A	83.57AB	84.10AB	84.9A
140	86.30 A	81.20B	86.47A	84.66A
160	86.53 A	86.60A	86.47A	86.53A
Means	86.64A	83.79B	85.68AB	
	L	Q	L*Q	
SE	1.34	1.34	2.32	
LSD (0.05)	2.81	2.81	4.87	

Table 11: Effect of flow rate, furrow length and the interaction between flow and length on storage efficiency (%)

Furrow length (m)	**Flow rate (lit/s)**			**Means**
	2.7	**2**	**1.5**	
120	88.67AB	98.77A	97.57A	95.00A
140	84.53AB	91.37A	88.47AB	88.12AB
160	74.40B	87.43AB	97.03A	86.29B
Means	82.53 B	92.52A	94.36A	
	L	Q	L*Q	
SE	4.13	4.13	7.15	
LSD (0.05)	8.67	8.67	15.02	

Table 12: Cross-sectional area and furrow length with different rates

l/s	Before irrigation for 120 m				After irrigation for 120 m			
	top	middle	tail	Average	top	middle	tail	Average
2.7	0.086	0.0764	0.084	0.0821	0.0988	0.0836	0.0745	0.0856
2	0.077	0.0723	0.0804	0.0766	0.0894	0.0824	0.0688	0.0802
1.5	0.0798	0.0678	0.0625	0.07	0.0914	0.0731	0.0594	0.0746
l/s	Before irrigation for 140 m			Average	After irrigation for 140 m			Average
2.7	0.0671	0.0887	0.0917	0.0825	0.0744	0.0929	0.0765	0.0813
2	0.0818	0.0703	0.0963	0.0828	0.0895	0.075	0.084	0.0828
1.5	0.077	0.0768	0.0836	0.0791	0.0884	0.087	0.0904	0.0886
l/s	Before irrigation for 160 m			Average	After irrigation for 160 m			Average
2.7	0.0685	0.0659	0.0685	0.0676	0.0815	0.0713	0.0627	0.0718
2	0.0639	0.0585	0.0692	0.0639	0.0768	0.06	0.0578	0.0649
1.5	0.0581	0.0651	0.0663	0.0632	0.0685	0.0702	0.0615	0.0667

Storage efficiency (Es): The effect of furrow length on Es was significant ($p<0.05$). There were two groups in which the means were not significantly different from one another. Mean values of Es were 195, 88.12 and 86.29% for furrow length of 120,140, and 160 m, respectively (Table 11, Fig. 4, 5). Storage efficiency had shown decreasing trend as furrow length increased. Effect of flow rate Es were significant ($p<0.05$). There were no significant pair-wise differences among the means. Storage efficiency had shown increasing trend as flow rate decrease and mean of ES were 82.53, 92.52 and 94.36 % for flow rates of 2.7, 2 and 1.5 lit/s, respectively (Table 11). Interaction effects between furrow length and flow rate were significant ($p<0.05$). There were three groups in which the means were not significantly different from one another. The maximum Es 98.77% was achieved for 2 lit/s on 120 m long furrow and the minimum74.4% was obtained for 2.7 lit/s flow rate and 160 m furrow length. (Holzapfel et al, 2010). Recall that Assefa et al (2017) found that all indices except deep percolation ratio and storage efficiency had shown an increasing trend as flow rate increased.

Furrow cross-sectional area: The average furrow crosses profiles for different flow rates, before and after irrigation, were shown in Fig. 5, 6, 7. Field data from three irrigations on changes of furrow cross-sectional area indicated that net rates of soil

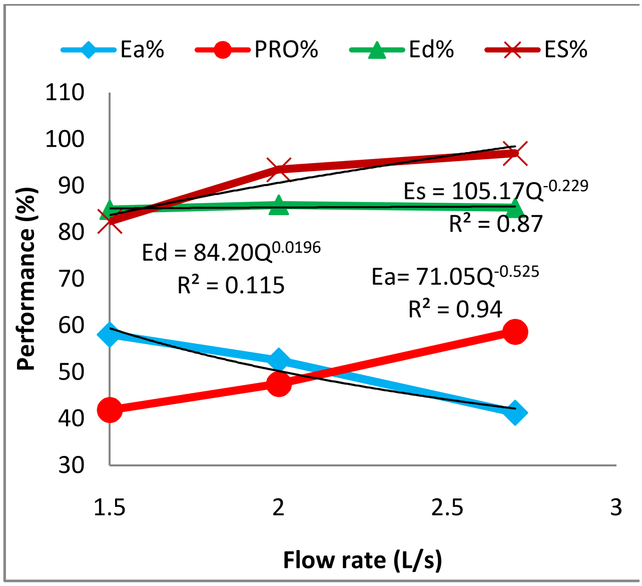


Fig.4: Relationships between flow rates and performance

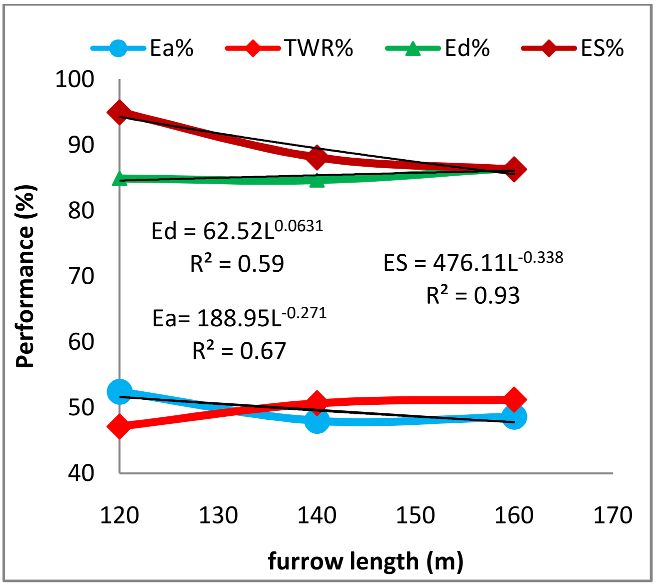
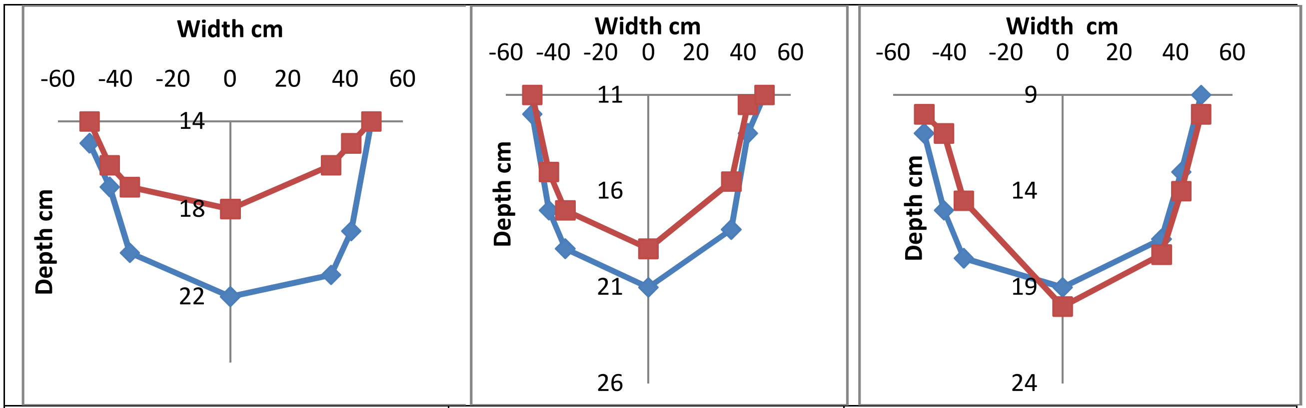


Fig.5: Relationships between furrow length and performance



Furrow Top

Furrow Mid

Furrow Tail

Fig.6: Average Cross sectional Area at top, mid and tail of 160 m furrow-length

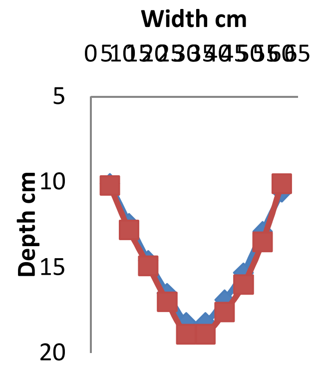


Fig.7: Average Cross sectional Area for furrow-160 m length

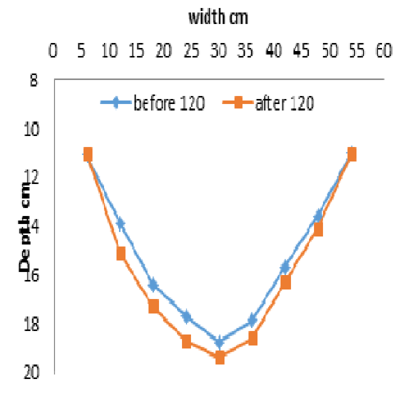


Fig.8 : Average Cross Sectional Area for furrow -140 m length

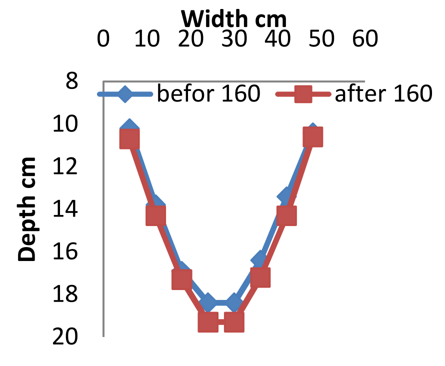


Fig.9 : Average Cross Sectional Area for furrow length 120 m

loss in the upper part of the furrow that were up higher than the average net rate for the whole furrow. The soil loss was related to the in flow rate by power functions, and soil loss is inversely related with furrow length. It is noted that erosion occurs in the -bottom part of the furrow of 4.7, 3.3 and 4.4% for 120, 140 and 160 m furrow lengths.

The models were obtained from the relationship of the furrow depth with the cross-sectional area.

i- For length of 120 m: Before irrigation: $Ao = -0.013y2 + 0.763y + 6.86$ ($R^2 = 0.99$), and after irrigation: $Ao =-0.014y2+0.835y+6.82$(R^2=0.98) (Fig 7).

ii-For length of 140 m: Before irrigation: $Ao = -0.011y2 + 0.714y + 5.74$ ($R^2 = 0.98$), and after irrigation: $Ao=-0.012y2+0.786y+5.32$(R^2=0.98). (Fig 6).

iii- For length of 160 m: Before irrigation: $Ao = -0.019y2 + y + 4.81$ ($R^2 = 0.99$), and after irrigation: $Ao=-0.02y2+1.059y+4.82$(R^2=0.99). (Fig 5).

Conclusions

Empirical power functions for water front advancement in the furrow have been fitted for different inflow rates under existing lengths of the farm. This study showed that the use of different furrow length and flow rate has shown different outcomes. Flow rate has a significant effect on irrigation performance indicators. The decrease of flow rate from 2.7l/s to 1.5l/s has certainly improved the Ea, TWR, Es, and Ed.

Optimum furrow length can be calculated giving maximum attainable application efficiency. Higher uniformity of application can be achieved by adopting a lower flow rate of 1.5 L/s in length 120 m with average application efficiency of 59.29%. The use of 2.7 l/s was seen with highest TWR, lowest adequacy of water in a furrow of 160 m. In this study, the use of short furrow length was the major contributor of water loss through surface runoff. In open-ended short furrow utilization, runoff losses were greater over deep percolation loss. Hence, runoff reuse systems are kindly relevant to improve irrigation efficiencies and conserve water resource. A flow rate of 2.7 L/s or more should be avoided since it results in poor uniformity and soil erosion.

The overall output of this study imply that application of continuous flow rate plays a decisive role on the improvement of performance parameters of irrigation systems with the best performances is maintained with flow rates close to the minimum allowable non-erosive levels, while the length did not remarkably interfere in the process of improvement of performance parameters. In soils with low infiltration rates, both percolation and runoff losses can be easily minimized with proper combination of flow rate and field length.

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