P-ISSN: 2798-1134 | E-ISSN: 2797-3549 | DOI: 10.52562/injoes.2023.515

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Evaluation of Irrigation Water Application Techniques at Omo Kuraz Left Bank Canal, SNNPRE, Ethiopia

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Received: 29 December 2022 / Accepted: 25 February 2023 / Published: 28 February 2023

Abstract: Water loss from furrows can be due to runoff, seepage and deep percolation which may cause yield reduction. This study focuses on the evaluation of irrigation water application techniques and employed experimental observation which included 30 test observations using the bund, cut-off, cut-back, surge, and portable structure techniques. The experiments were carried out in two blocks; block A with 50 m furrow length and that of block B with 100 m furrow length. The experimental design was a randomized complete block design with three replications. The analysis was done using surface irrigation evaluation model and SAS software package. The results of the study showed that at block A, highest application efficiency of 87.0% was obtained with surge flow and followed to this cut-back recorded 86.6%; whereas the lowest application efficiency of 75.00% was obtain by bund technique. Storage efficiency of surge and cut-back recorded 99.00%. The lowest was obtained by bund (88.9%). The distribution uniformity of surge was highest (84.1%) whereas bund technique gave 71.0% of lowest distribution efficiency. At block B, surge registered the highest application efficiency and distribution uniformity of 66.0% and 59.57% whereas; bund technique records the lowest application efficiency of 60%. The surge and cut-back were more efficient in the field recovery of storage requirement resulted above 99.0%. The statistical analyzed results showed that mean application efficiency of 75.69% was obtained using the surge technique; whereas the lowest application efficiency of 70.0% was obtained by the bund. The use of the surge technique reduces irrigation water loss from 30.0% to 24.3% compared to the local bund technique. This is due to the surge performed better in terms of advance rate and efficient moisture content. With the surge, the highest mean DU of 68.07 % was obtained, while the bund technique had the lowest DU (58.32%). Therefore, adoption of the surge is a promising water application and management practice in sugar cane plantation at Omo Kuraz.

Keywords: Application efficiency, distribution uniformity, application technique, surge, cut-back

INTRODUCTION

Water is the most essential component of nature; which brings and sustains life on land. This valuable natural resource is, mainly used for agriculture, recreation and industrial purposes. Industry expansion and population growth aggravate the utilization and demand of water which increased pressure on the water resources. The major portion of the water resource is used in the agriculture sector for irrigation purposes to enhance the scheme productivity; therefore, available water and land resources should be optimized to maximize farm production and income (Ogbolumani & Nwulu, 2022).

The development of irrigation and agricultural water management holds significant potential. The potentially irrigable land of Ethiopia is estimated to be about 5.3 million ha (Dejen, 2015). However, Ethiopia has huge cultivable land; the current irrigation development is about 0.7M ha (Awulachew & Ayana, 2011).

In surface irrigation systems furrow irrigation method is common and has minimum application efficiency. Besides delivering the irrigation water for the user, efficient management of irrigation water is also important, as the new sources of irrigation supplies become scarce and new irrigation development work requires huge investment. Irmak et al. (2011) detailed that the potential application efficiencies for well-designed and well-managed conventional furrows are 45-65%, for surge furrow 55-75% and furrow with tail water reuse 60-80%.

There are several factors available that influence the furrow irrigation application efficiency. These may include the furrow length, the flow rate and furrow slope. Eldeiry et al. (2005) found that furrow length and application discharge are the main management and design parameters affecting the application efficiency in furrow irrigation in clayey soils.

Salih (2014) studied the effect of surge, cut-off, cut-back and bund techniques on long furrow irrigation systems. The study was conducted in three sugar state sites and the highest application efficiency of 74% was obtained with surge flow, whereas the lowest application efficiency of 59% was obtained by the cut-off technique.

Irmak et al. (2011) describe that water losses during surface (furrow) irrigation through runoff losses can be significant if tail water is not controlled and reused. In cases where runoff water is recovered and reused, the volume of irrigation water delivered to the farm or field should be adjusted to account for the net recovered tail water. Irrigators commonly block the lower end of furrows to prevent runoff. Especially application efficiency maximizing techniques like bunds or check dams are susceptible to erosion and submergence.

The primary objective of this study is to minimize application water loss of furrow system and to improve field application uniformity throughout the farm in Omo Kuraz Left bank sugar estate large scale irrigation scheme. A suitable and portable field ditch water control structure also was designed. These objects were also achieved by a set of evolution experiments.

MATERIALS AND METHODS

Description of the Study Area

This study was located between 6° 4' 0" – 6°15' 0" latitude and 35°55' 30" - 36°4' 30" longitude in Southern Ethiopia. The elevation of the area ranges from 430 – 480 masl. The mean minimum and maximum air temperatures are 23.5°C and 35.7°C, respectively. The annual rainfall is 714.24 mm. Figure 1 shows the location of the study.

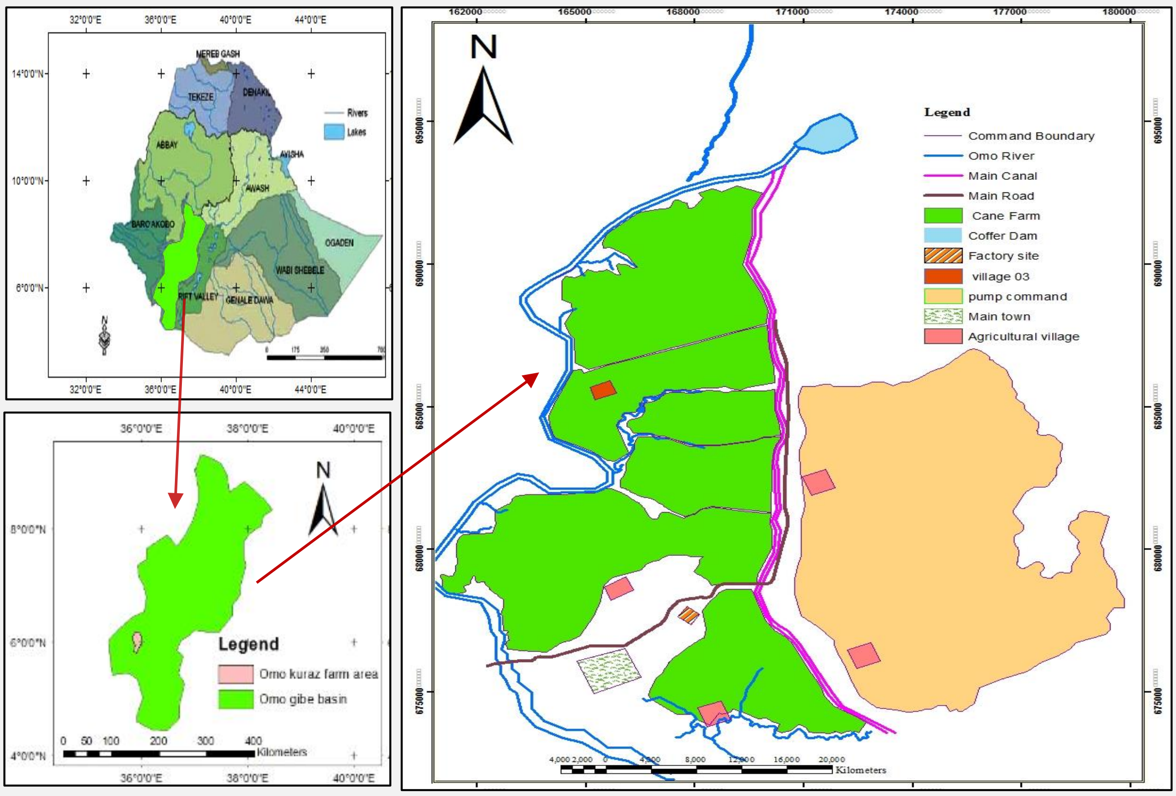

Figure 1. Location map of the study area

Climatic conditions

As shown in the Figure 2 below the mean maximum monthly rainfall is around 260 mm. The month with the highest precipitations is at April. The annual average maximum and minimum temperature are 35.7°C and 23.5°C respectively.

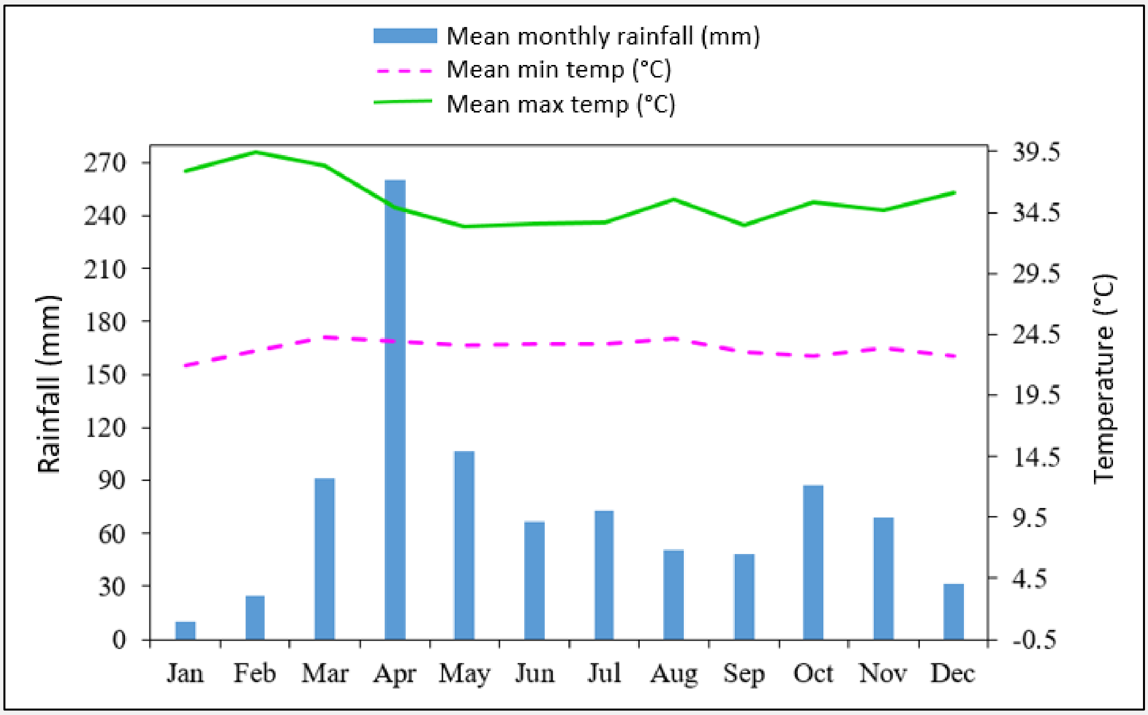

Figure 2. Climate of Omo Kuraz irrigation scheme

Water sources

The source of water for the scheme emanates from the cofferdam of the Omo River. According to (Mojira et al., 2021) study the mean annual discharge at Kuraz dam site has been estimated at approximately 750 m^3/s while the monthly average is about 200m^3/s from January to march, increasing up to 1000 m^3/s and 1350 m^3/s from May to September.

Soil type

Most soils of the Omo Kuraz Sugar Estate cane fields are comparatively recent alluvial origin and are classified as Cambisols. On average, the clay soil types have 40–51% clay in the top 0.6 m. For the heavy clays, the general range is 55-70%. The clay over loamy soils has 35 – 46% clay. Based on the total available water capacity, there are four distinct soil textural groups exist, Heavy (vertic) clays (V), Clays (C), Clay over loam (CL) and Sandy; very gravelly; pumice. Soil bulk density is mostly < 1.66 g/cm^3 (Mojira et al., 2021).

Data Collection

Primary Data

The flow was measured by using current meter and 90° triangular v-notch device and current meter. The dimension of experiment plot size, furrow lengths for each block (block A and block B), The Furrow spacing, slope and shape were also surveyed by meter tap. Besides, Advance and recession time were monitoring using a stop watch

Secondary Data

The secondary data were soil data, furrow design data, feeder ditch design data, design discharge for a plot of land, irrigation interval and crop water requirement including all metrological data. The collection method was through a legal request letter.

Materials used

The materials used in this study were surveying types of equipment (meter tap, total station and leveling), v-notch thin plate, stopwatch, siphon, flex flume, absolute (analog) manometer and gauged bucket current meter.

Experimental Design

The main treatment materials were furrow length and application techniques. The two furrow lengths, 50 m and 100 m were randomly selected for test. The techniques were five in number (bund, cut-off, cut-back, and surge and use portable technique). All these were randomly tested at each furrow with three replications.

The total time to reach the end of the furrow 50 m and 100 m furrow length was measured for treatments with two cycle times for each. There were 6min and 10.2 min for 50 m and 20 min and 25 min for 100 m furrow length. The operation was done using gated pipe (flexi flue) and the flow could be created by shutting and off the orifice with it cup manually. The subsequent irrigation discharge 0.45l/s were repeated for the second irrigation and the same procedure was revised for all the replications. The flow rate 4.5l/s reduced to the cut-back inflow rate of 2.25l/s when water advance to a distance of 30 m and 60 m in blocked 50 and 100m of furrow ends respectively. The values of furrow length were approximately 60% of the original furrow length. The bund was specified on the furrow geometry. The size was 30 cm width, 20 cm height and constructed from earthen materials. The function of portable structure was similar with bund technique but instead of earth material using portable sheet metal easier for operation and functioning to minimize more water iterance to the soil by reduce the intake opportunity time.

Layout of field experiment

The experiment site covers 1687.5 m2 of total area. The defined sketches and coordinate of experiment site was shown in Figure 3.

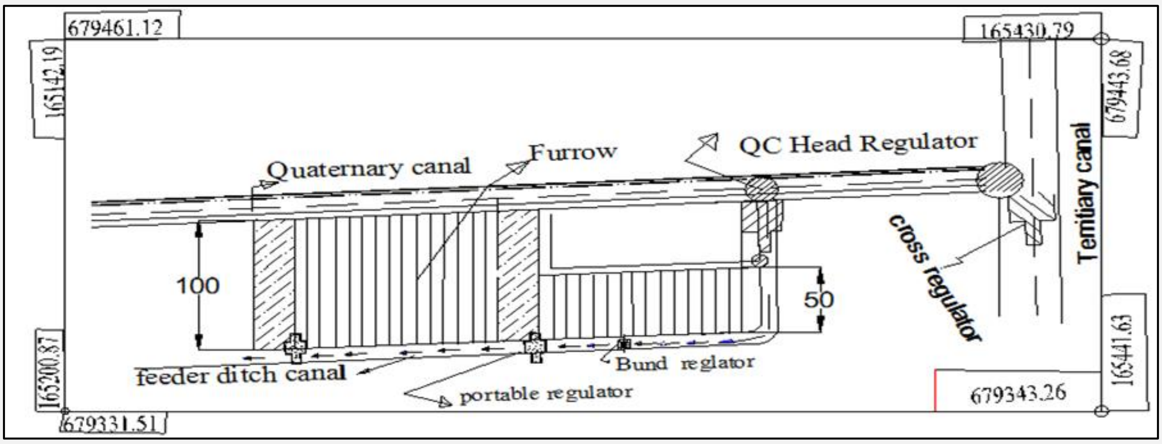

Figure 3. Layout of field experiment area

Determination of Field Evaluation Parameters

The methods used for this study consisted of five irrigation water application techniques as bund, cut-off, cut-back, surge and portable structure. Among the listed techniques, the bund and cut-off are currently under practice in the study area. Cut-off cut-back, bund, surge and portable flow control structures were evaluated for their efficiency in this study. The measurements included were furrow and feeder ditch dimensions (cross-section), discharge, advance, recession and infiltration. The evaluation procedure was preceded by defining the cross-sectional area at the field inlet using furrow and feeder ditch geometry parameters computed from field survey data and the data was evaluated by Surface irrigation evaluation model (advance time relation) and SAS software packages.

Soil moisture content determination

The soil moisture content measurements before irrigation were made by a gravimetric method which involves collecting soil samples with auger, weighing the wet soil samples, removing the water by drying in an oven at 105 °C and re-weighing the sample to determine the amount of water removed.

Soil moisture content in each sample was determined using:

$$\theta dw = \frac{Wws - Wds}{Wds} * 100 \tag{1}$$

Where, θdw is the soil moisture content on weight basis (%), Wws is the weight of the wet soil sample (g), Wds is the weight of the soil sample after oven drying (g) and then the moisture content of soil samples were converted to the volumetric water content (θv) by multiplying with bulk density (ρb) as:

$$\theta v = \theta dw * \rho b \tag{2}$$

Soil moisture content was also expressed in terms of equivalent ($\frac{mm}{m}$) depth (Humpherys, 1968) as:

$$\text{Equivalent depth } (\frac{\text{mm}}{m}) = 10 * \theta v\ (\%) \tag{3}$$

Measurement of Hydraulic Parameters

Furrow Dimension

The experiment plot area was grouped into two blocks (A and B). Block A is provided with a 50m furrow length and block B with a 100 m furrow length. The flow in the distribution canal, feeder ditch and furrow cross section area was estimated by a mean-section method.

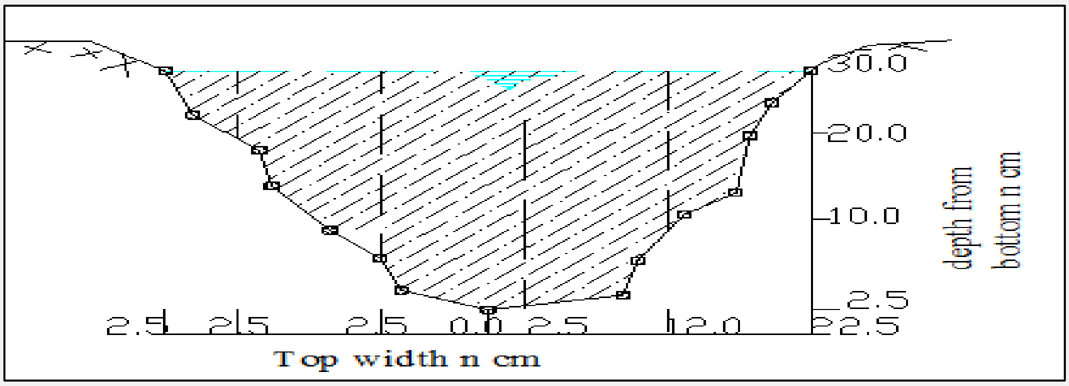

Figure 4. Furrow cross-section shape

Measuring Advance and Recession time in furrow hydraulics Phases

The flow time was rescored subsequently in the 6.25 m intervals of furrow section for block A of 50 m furrow length and 12.5 m intervals of furrow section for block B of 100 m furrow length. For one furrow length, 9 observations and a total of 18 sets of observations were made.

Discharge measurement

The flow rate into furrows was measured using 90° triangular v-notch devices. The inlet and intermediate discharges during the cut-off, bund and portable structure techniques were measured using the v-notch device. The discharge characteristics of triangular v-notch thin plate weirs were determined as described by Shen (1981).

$$Q = 4.28C \tan(\frac{\theta}{2})(h + k)^{5/2} \tag{4}$$

Where Q is discharge (cfs); C is discharge coefficient; θ is notch angle; h is head in (ft); k is head correction factor (ft).

Siphon discharge measurement

Inflow rate through gated pipe with velocity (Abdel & Adeeb, 2014) narrates as stated below:

$$Q=C*A*(2gh)^{1/2} \tag{5}$$

Where h-is the head deference between water surface of quaternary canal and siphon outlet (cm), C-is discharge coefficient (C=0.613 for siphon, 0.8 for concrete pipe), g- gravitational acceleration (g=981 cm/sec^2), A-cross sectional area of pipe and Qs- is the water flow through the siphon (lit/sec).

Gate discharge (flex flume)

The discharge of siphon and Flexi flume were determined at different pressure-heads. The following formulas were used to calculate the average discharge and discharge range.

$$\text{Qmean} = \frac{\text{Qmin+Qmax}}{2} \tag{6}$$

$$\text{Qrang}\pm\% = \frac{\text{Qmin or Qmax - Qmean}}{\text{Qmean}} * 100 \tag{7}$$

$$Qav = \frac{\sum Q}{n} \tag{8}$$

Where Q is discharge (l/s); n is number of measured points; Qmean is mean discharge (l/s), Qmin is minimum discharge (l/s), Qmax is maximum discharge (l/s); ∑Q is summation of discharge (l/s); Qav is average discharge (l /s); and Qrang ± is discharge variation (%).

Data Analysis and Interpretation

Determination of Infiltration Parameter

Surface Irrigation Models of empirical Water Advance-Time Relationships explained by Kostiakove (1932). The water infiltration was also measured by making water advance (Singh & Chauhan, 1973).

$$\mathrm{I} = \mathrm{at}^{\mathrm{b}} \tag{9}$$

Where I is the cumulative infiltration m^3/m/m; t is intake opportunity time min and for any point x,τ =t-tx where t is the current time from the commencement of the irrigation and tx the time that advance reached to the point x, a and b are constants.

Determination of irrigation efficiency

The application losses were determined in terms of application efficiency (Losses = 1-E_a) as described by Shaikh et al. (2015).

Application Efficiency (E_a)

The Application Efficiency (Ea) is a measure of the percentage of applied water that contributes to the plant requirement. According to Burt et al. (1997), E_a can be computed as the ratio of the volume of irrigation water stored in the root zone, represented by W_s, to the total volume of water applied to the field, represented by W_f, multiplied by 100. Therefore, the mathematical expression for E_a is:

$$\mathrm{E_a} = \left(\frac{\mathrm{W_s}}{\mathrm{W_f}}\right) * 100 \tag{10}$$

To calculate W_s, it is important to note that water infiltration within the furrow is not uniform across the four subdivided furrow reaches (z_1, z_2, z_3, and z_4). Water infiltrated below the moisture deficit level (Zd = 10.2 cm) is considered as deep percolation. The total volume of water infiltrated is the sum of the volume of water infiltrated up to the point of the moisture deficit level (Z_d) and the volume of water infiltrated above Z_d. The volume of water captured in the root zone is equal to the product of furrow length, soil moisture deficit, and furrow spacing, as given by equation (11) in the passage. The total volume of water applied to the field, W_f, can be computed using the discharge rate of water delivered to the field, denoted by Q_f, and the duration of the irrigation, as given in equation (13).

$$Volume = \left(\frac{d_1+d_2}{2}\right) * L * unit\ width\ (W) \tag{11}$$

$$Vrz \sum_{Z=1}^{Zn}(Z) \quad \text{, Where Z=Zd, and Z<Zd} \tag{12}$$

$$W_f = Q_f * time\ of\ irrigation \tag{13}$$

Distribution efficiency (E_d)

The term Distribution Efficiency (E_d) is defined as the ratio of the average depth of water infiltrated, denoted as d_{av}, to the sum of the absolute differences between the depth of water infiltration at each location (d_i) and the average depth of infiltration (d_{av}) for all locations, divided by the total number of locations (n). Mathematically, this can be expressed as:

$$E_d = 1 - \frac{\sum(|d_{av} - d_i|)}{n\, d_{av}} \tag{14}$$

Distribution Uniformity absolute low (D_{Ua})

The Distribution Uniformity absolute low (D_{Ua}) is calculated as a percentage using the ratio of the minimum infiltrated depth or volume (in mm or m^3, respectively) denoted as V_{min} to the mean depth or volume of water infiltrated over the furrow length (in mm or m³, respectively), denoted as V_{av}. This calculation is expressed mathematically as:

$$D_{Ua} = \left(\frac{V_{min}}{V_{av}}\right) * 100 \tag{15}$$

Distribution Uniformity (D_U)

The concept of Distribution Uniformity (D_U) is defined as the ratio between the amount or depth of water in the lowest quarter of a field and the average depth of water infiltrated over the entire field. Jurriëns et al. (2001) formulated the equation for computing D_U as follows:

$$D_u = D_{avlq}/D_{av} \tag{16}$$

Storage (Requirement) efficiency (S_R)

The Storage Efficiency (S_R) is a metric used to determine the extent to which the root zone has been effectively refilled with water. It is calculated as the ratio of the actual depth or volume of water stored in the root zone, denoted as ws, to the total depth or volume of water required to replace the soil moisture deficit, designated as VRZ, multiplied by 100. The mathematical expression for this equation is:

$$S_R = \left(\frac{\text{ws}}{\text{VRZ}}\right) * 100 \tag{17}$$

Deep percolation Ratio (D_{pr})

The Deep Percolation Ratio (D_{pr}) is defined as the proportion of the water applied to the field, denoted as Ws, that infiltrates the soil and percolates below the root zone. It is calculated as the ratio of the depth or volume of water that percolates below the root zone, designated as Vdp, to the total depth or volume of water applied to the field. The mathematical expression for this equation is:

$$D_{pr} = \left(\frac{Vdp}{\text{WS}}\right) \tag{18}$$

RESULTS & DISCUSSION

Determination of Infiltration Parameter

Advance rate and opportunity time

The advance distance and advance time of 50 m furrow length for surge, cut-off cut-back bund and portable furrow irrigation application techniques were determined as shown in Figure 4. Issaka & Issah (2015) reported that surge flow can provide a significant importance in the efficiencies and uniformity of surface irrigation. Additionally, cut-off technique had relatively high advance rate of (3.05 m/min), recession time (23.40 min) and opportunity time of (7.67 min).Whilst the Bunds technique recorded the slowest advance rate (2.80 m/min), recession time (23.4 min) and opportunity time (6.67 min) as shown in Figure 5.

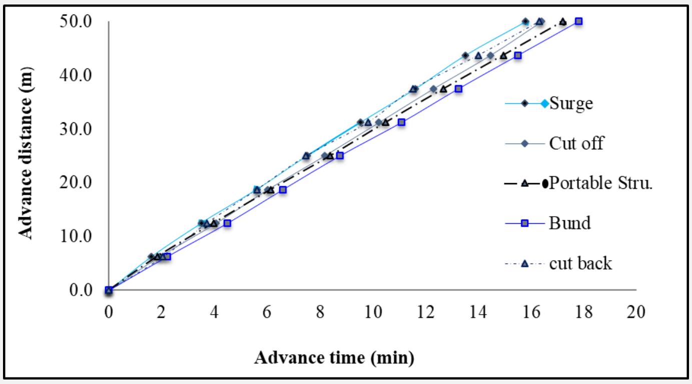

Figure 5. The advance curve at block A (50 m)

Results from block B (100 m) furrow length showed that used surge technique recorded the fastest advance rate (2.22 m/min), recession time (53.9 min) and intake opportunity time (8.9 min). This may be due to the fact that subsequent use surge technique had the potential to control both the time required for water to flow across the field advanced in time and infiltration rate, thereby reducing the amount of percolated water at furrow end and achieving better uniformity in soil moisture distribution.

Use cut-back technique also had a high advance time (2.21 m/min), recession time (53.8 min) and opportunity time (8.45 min). Additionally, the cut-off and portable technique had similar values (2.20 m/min), recession time (52.8 min) and an opportunity time of (7.4 min). Whilst in the bunds technique an advance rate (2.18 m/min), recession time 49.4 and opportunity time (3.92 min) were recorded Figure 6.

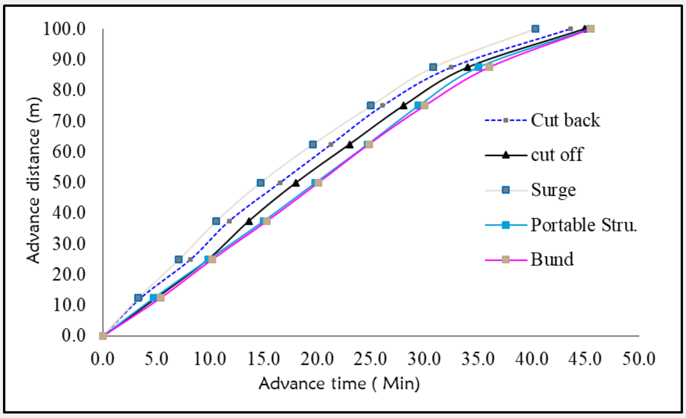

Figure 6. The advance curve at block B (100 m)

Constants (a) and Exponent (b) in Infiltration function

The best-fit parameters for the infiltration rate curve were the infiltration constant and exponent. The infiltration rate followed a power function, with a value of 2.128 for the constant and 0.735 for the exponent. Initially, the infiltration rate was high but gradually decreased over time. During the first 2 hours, the infiltration rate was 1.48 cm/min per cm of depth, while in the later hours, it decreased to 0.38 cm of infiltration depth. This behavior was due to the pore space characteristics of the topsoil, which facilitated flow movement. Abdulkadir et al. (2011) noted that the infiltration characteristics derived from ring infiltration data accurately reflected field conditions. Figure 7 depicts the infiltration functions of the field, which were modeled based on advance time relation mode.

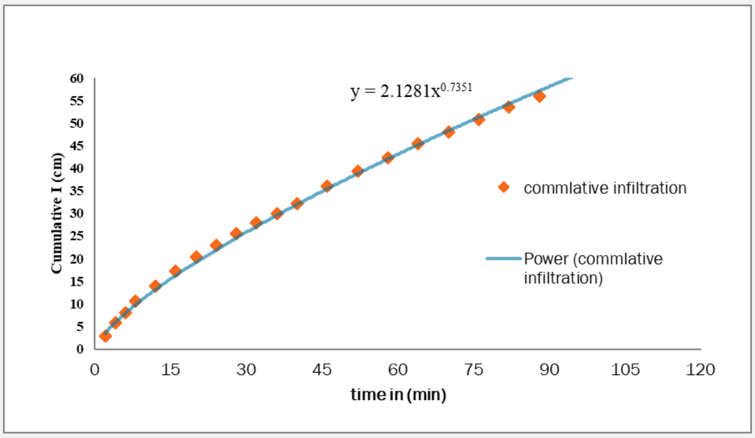

Figure 7. Infiltration time curve of irrigation field

Determination of irrigation efficiency

Bund technique efficiency on the response of 50 m furrow length

Application efficiency 75.0%, storage efficiency 88.97%, and distribution efficiency 86.00%, distribution uniformity 71.00%, distribution Absolute 65.0% and deep percolation ratio 0.31 of the furrow profile. High water loss throughout deep percolation occurred. Elsheikh et al. (2014) reported that the hydraulic characteristic of the bund technique increases deep percolation losses, and this leads to minimizes application efficiency and distribution efficiencies. Issaka & Issah (2015) also similarly described that uniformity of water distribution using the bund approach is poor due to high deep percolation loss from starting point of irrigation up to a low quart of field. This management practices on the tail reach of furrow shown significant amount during these practices the application of the delivered furrow water have large amount than the necessarily stored root zone. After the advance phase recovered the necessary furrow portions it takes ascertain time to control water and not easy as in the water management operation.

Cut-off technique efficiency on the response of 50 m furrow length

Application efficiency 79.98%, storage efficiency 92.59%, and distribution efficiency 75.75%, distribution uniformity 79.09%, distribution Absolute 79.00% and deep percolation ratio 0.21 of the furrow profile. This cut-off technique had better irrigation efficiency in terms of application efficiency and distribution uniformity than the bund technique. This might be due to the water ponding formations and require high recession time to furrow end as a block. Deep percolation losses were decreased from 0.25% to 0.16% when using cut-off compared with bund irrigation water application technique.

Abdelmoneim et al., (2019) similarly described in the case of cut-off irrigation technique the delivered amount records low value, because flow was stopped when the waterfront reached the lower end of the furrow.

Cut-back technique efficiency on the response of 50 m furrow length

This cut-back technique had better irrigation efficiency in terms of application efficiency and storage efficiency than bund and cut of techniques. It was minimized 26% and 17.22% of water loss by bund and cut-off water management operation to difference level of 12.68% and 3.9% respectively. The advance and infiltration opportunity time of cut-back technique significantly difference from bund and cut-off time techniques. This is also the reason for the greater value of application and storage efficiencies. This finding is similarly supported by Evans et al. (1995) who stated that cut-back technique gave higher application efficiency than other traditional practices (bund and cut-off).

Surge technique efficiency on the response of 50 m furrow length

Application efficiency was 87.00%, storage efficiency 99.9%, distribution efficiency 87.0%, distribution uniformity 84.10%, distribution Absolute 82.0% and deep percolation ratio 0.13% of the furrow profile. The surge technique gave the highest irrigation efficiency in terms of application efficiency and distribution efficiency storage efficiency than bund cut of and cut-back techniques, but storage efficiency was obtained in similar value of cut-back technique. These results could be attributed to the long contact time and at the same time decreased runoff losses, which gave the better opportunity for water to enter the soil. This is due to the presence of high advancing and infiltration opportunity time of surge water application technique. Similar results were obtained by Salih (2014) reported that the higher advance rate reduces the difference in take rate opportunity time between the head of the furrow and the lower end.

Portable structure technique efficiency on the response of 50 m furrow length

Application efficiency was obtained 76.51%, storage efficiency 90.68%, and distribution efficiency 86.00%, distribution uniformity 72.00%, distribution Absolute 71.00% and deep percolation ratio 0.29% of the furrow profile. The portable technique gives the lowest irrigation efficiency next to bund technique. From the delivered water 23.5% of water was lost, 14% of water was evenly distributed and 28% of water was not uniformly distributed. These results could be attributed to the short contact time and at the same time increase deep percolation losses, which gave the lowest intake opportunity time for water to enter the soil. This is due to the presence of low advancing and infiltration opportunity time which net to bund technique.

Bund efficiencies on the response of 100 m furrow length

Application efficiency 60%, storage efficiency 87.54%, and distribution efficiency 52.0%, distribution uniformity 39.00%, distribution Absolute 35.00% and deep percolation ratio 0.377 of the furrow profile. This technique was observed in the lowest irrigation efficiencies as described in block A of 50 m furrow length. Lower quarter furrow portion was under deficit and an evenly distributed throughout deep percolation was occurred. This was recovered 75 up to 100-meter row lengths. The management practices on the tail reach of furrow shown a significant amount during this practice the application of the delivered furrow water have a large amount than the necessarily stored root zone.

Cut-off efficiencies on the response of 100 m furrow length

Application efficiency was 62.0%, storage efficiency 99.85%, and distribution efficiency 53.00%, distribution uniformity 56.44%, distribution Absolut 55.00% and deep percolation ratio 0.382 of the furrow profile. This cut-off technique had better irrigation efficiency in terms of application efficiency and storage efficiency than the bund technique. The more advancing and intake opportunity time infiltration also increases the value of application and storage efficiencies. Irrigation water losses were decreased from 40% to 38% when using cut-off compared with bund irrigation water application technique. The lower quarter furrow portion was under deficit and an evenly distributed throughout deep percolation occurred. This management practices on tail reach of furrow shown significant amount during these practices the application of the delivered furrow water had large amount than the necessarily stored root zone.

Cut-back efficiency on the response of 100 m furrow length

Application efficiency was 62.38%, storage efficiency 99.8%, and distribution efficiency 54.85%, distribution uniformity 57.89%, distribution Absolut 57.0% and deep percolation ratio 0.375 of the furrow profile. This cut-back technique has better irrigation efficiency in terms of application efficiency and storage efficiency than bund and cut-off techniques. It minimizes 40.00% and 38.0% of water loss of bund and cut-off water management operation to 37.62%. This may be due to the water ponding formations and require high recession time to furrow end as block. This is also the reason for greater value of application and storage efficiencies. This finding is similarly founded by Evans et al. (1995) who stated that cut-back technique gave higher application efficiency than other traditional practices (bund and cut-off).

The lower 12.5 m length furrow portion was under deficit and an evenly distribute throughout deep percolation was occurred. This management practices on the tail reach of furrow shown significant amount during these practices the application of the delivered furrow water have large amount than the necessarily stored root zone. After the advance phase recovers the necessary furrow portions it takes a sufficient infiltration time and water flow was relatively better in a cut-off water management operation.

Surge technique efficiency on the response of 100 m furrow length

Application efficiency was 66.00%, storage efficiency 99.9%, and distribution efficiency 51.00%, distribution uniformity 59.57%, distribution Absolut 59.00% and deep percolation ratio 0.33% of the furrow profile. Surge technique minimizes irrigation water loss of locally used techniques (bund and cut- off) by 6.00% and 3.68% respectively. These results could be attributed to the long contact time and at the same time decreased runoff losses, which gave better opportunity for water to enter the soil. This is due to the presence of high advancing and infiltration opportunity time of surge water application technique. Similar results were found by Salih (2014) reported that the higher advance rate reduces the difference in take rate opportunity time between the head of the furrow and the lower end.

The advance time was obtained at 45.00 min and intake opportunity time was 8.9 min. The lower 12.5 m length of furrow portion the advance was more rapid it leads to more uniform distribution of water along the furrow compared with the local technique water management practices. During this practice, the application of the delivered furrow water has a large amount than the necessarily stored root zone.

Portable structure efficiency on the response of 100 m furrow length

Application efficiency was obtained 61.20%, storage efficiency 98.16%, and distribution efficiency 54.45%, distribution uniformity 50.2%, distribution Absolut 56.1% and deep percolation ratio 0.383 of the furrow profile. The portable technique gave the lowest irrigation efficiency next to bund technique. From the delivered water 38.8% of water was lost, 43.35% of water was evenly distributed and half of water was not uniformly distributed. These results could be attributed to the short contact time and at the same time increased deep percolation losses, which gave the lowest intake opportunity time for water to enter the soil.

The advance time was obtained at 45.40 min and intake opportunity time was 7.40 min. and the remained was under excess condition. The lower 25 m length of furrow portion was under deficit, but it was insignificance amount compared with the local bund technique water management practices. During this practice, the application of the delivered furrow water had a large amount than the necessarily stored root zone. After the advance phase recovers the necessary furrow portions it takes insufficient infiltration time and water flow. The total delivered amount of irrigation water was 12.258 m^3, water stored in the root zone 7.509 m^3, and the volume of irrigation water necessarily require was similar with all techniques of technique 7.65 m^3.

Statistical analysis result of Furrow flow hydraulic parameters

Volume of water applied to the field (w_f)

The response of applied volume water was affected both with main and interaction effect of application techniques and furrow lengths showed a highly significant (0.0027, $P<0.05$) influence on the amount of total delivery water. The maximum amount of the interaction effect on furrow length and techniques was observed (12.258 m^3) at level 7, 8 and 10 of 100 m furrow and use cut-off, cut-back and portable structure technique whereas the lowest amount of water (4.197 m^3) was obtained in level 1 of 50 m furrow and use bund technique as described in Table 1 below.

Table 1. The response of the combination of furrow length to techniques

S/N	Combination of furrows and Technique Effect	Wf (m^3)	Vmin (m^3)
1	F1T1	4.197	0.450
2	F1T2	4.247	0.445
3	F1T3	4.509	0.450
4	F1T4	4.509	0.480
5	F1T5	4.239	0.450
6	F2T1	10.967	0.612
7	F2T2	12.258	0.434
8	F2T3	12.258	0.477
9	F2T4	11.610	0.478
10	F2T5	12.258	0.434

Note: - F1=50 meter furrow length in block A, F2 = 100 meter furrow length in block B, T1 = Bund technique, T2 = Cut-off technique, T3 = cut-back technique, T4 = Surge technique, T5 = Portable techniques, Wf=Total volume of delivered water to field, Vmin=minimum volume (per furrow spacing) of infiltrated water in the least-irrigated 25 percent of the field.

The minimum Infiltrated volume of water (V_{min})

The minimum infiltrated volume amount in the least quarter of the field (0.434 m^3) was obtained from furrow length of 100 m at the use of portable structure water application techniques. Minimizing the furrow lengths were resulted in a significant increment of infiltrated volume amount of irrigation water in the root zone but else decreases the deficit level of infiltration throughout the field (Table 1). The explanation was in accordance with the findings of Salih (2014) reported that the significant variation in infiltrated volume amount due to furrow shortening practices effect might be attributed to the relative advance rate differences in the ability of short furrows to distribute applied water in uniform with.

Actual water stored in the root zone (w_s)

Maximum significant amount of water actually stored in the root zone (7.42 m^3) was recorded to 100 m furrow length whereas the minimum was (3.56 m^3) obtained from 50-meter furrow length (Table 2). From the main effect of the field water application technique, the maximum significant amount of water actually stored in the root zone (5.735 m^3) was obtained in the surge technique.

Deep percolation volume (V_{dp})

Maximum deep percolation amount (3.7 m^3) was recorded in block B of 100m furrow length furrow whereas the minimum was (0.94 m^3) obtained from block A of 50-meter furrow length (Table 2). From the main effect of the field water application technique, the maximum significant V_{dp} (deep percolation volume) (2.99 m^3) was obtained in the bund technique, on the other hand, the minimum was (2.225 m^3) observed in the surge technique (Table 2).

Field Irrigation efficiency parameters

Application efficiencies (Ea %)

The result from the analysis of the two block furrows and water application technique showed in Table 3, Application efficiency (E_a) was very highly significantly ($P<0.001$) influenced by main effect furrow length. The maximum significant value (82.73%) was recorded in block A of 50 m furrow length whereas the minimum value (62.67%) was obtained from block B of 100 m furrow length. Reducing water loss from 27.15 % to 24.31% was also observed while using surge compared with cot off technique. Similarly, Issaka & Issah (2015) stated that surge flow can provide a significant improvement in the efficiencies.

Table 2. Results of furrow length and application techniques on infiltration parameter

S/N	Treatments	W_s in m^3	V_{dp} in m^3
	Furrow		
1	F1	3.56^b	0.94^b
2	F2	7.428^a	3.7^a
	LSD (5%)	0.52	0.45
	SE(+)	0.18	0.15
	Techniques		
1	T1	5.00^a	2.99^a
2	T2	5.589^a	2.68^b
3	T3	5.72^a	2.6^b
4	T4	5.735^a	2.225^b
5	T5	5.414^a	2.78^{ab}
	LSD (5%)	0.82	0.72
	SE(+)	0.28	0.24
	CV	12.8	19.2

Note: - F1=50-meter furrow length in block A, F2 = 100-meter furrow length in block B, T1 = Bund technique, T2 = Cut-off technique, T3 = cut-back technique, T4 = Surge technique, T5 = Portable techniques, W_s = volume of water stored in the root zone, V_{dp} = Deep percolation volume.

Distribution Uniformity (D_U %)

The maximum significant value (77.68 %) was recorded in block A of 50 m furrow length whereas the minimum value (52.39 %) was obtained from block B of 100 m furrow length (Table 3). From the main effect water application techniques, the maximum significant value in surge technique (68.07%) was obtained, on the other hand, the minimum value (58.32%) at bund water application technique. This might be due to the acceleration of the advance phase and due to the reduction in deep percolation losses obtained when using surge flow, furthermore bund technique encourages water to escape by the cracks beyond the root zone and seepage loss below the closed end furrow. Thus, the difference in intake opportunity time between the upper and lower ends of the furrow was less and resulted in a more uniform distribution of water intake over the length of the furrow (Humpherys, 1989). A similar conclusion was reported by Hamdy et al. (2003).

Storage Efficiency (SR %)

Storage efficiency of the two studied blocks was shown in Table 3 below. At block A with 50 m furrow length, a significant difference (0.0254, $p<0.05$) was observed among treatment means. The maximum significant value (97.06%) was recorded in block B of 100 m furrow length whereas the minimum value (94.40%) was obtained from block A of 50 m furrow length (Table 3). From the main effect water application techniques, the maximum significant value of 99.54% was obtained by surge and cut-back technique, on the other hand, the minimum value (78.20%) was recorded at bund water application technique (Table 3).

Deep percolation ratio (D_{pr})

Loss of water due to the deep percolation of the two blocks as shown in Table 3 below. The result from Block A with 50m and block B with 100m furrow length showed a significant difference, (0.022, $p<0.05$) observed among treatment means. The maximum significant value (0.37 %) was recorded in block B of 100m furrow length whereas the minimum value (0.21%) was obtained from block A of 50 m furrow length (Table 3). The result from the main effect water application techniques also highly significantly difference ($p<0.01$) the maximum significant D_{pr} value in used portable structure technique (0.33%) was obtained, on the other hand, the minimum D_{pr} value (0.23%) at cut-off water application technique (Table 3).

Table 3. Analysis result of field irrigation efficiency parameters

S/N	Treatments	E_a (%)	D_U (%)	S_R (%)	D_{pr} (%)
	Furrow				
1	F1	82.73[a]	77.68[a]	94.40[a]	0.21[a]
2	F2	62.67[b]	52.39[b]	97.06[a]	0.37[a]
	LSD (5%)	2.74	7.0	5.35	4.13
	SE(+)	0.93	2.38	1.8	1.4
	Techniques				
1	T1	70.0[b]	58.32[b]	78.20[b]	0.33[a]
2	T2	72.85[b]	67.04[ab]	96.19[a]	0.29[b]
3	T3	73.301[a]	67.40[a]	99.54[a]	0.27[b]
4	T4	75.69[a]	68.07[a]	99.54[a]	0.23[c]
5	T5	70.13[b]	63.05[b]	92.41[b]	0.29[ab]
	LSD (5%)	4.34	11.08	8.46	6.52
	SE(+)	1.47	3.75	2.87	2.2
	CV	4.80	13.90	7.70	3.08

Note: - F1=50-meter furrow length in block A, F2 =100-meter furrow length in block B, T1= Bund technique, T2=Cut-off technique, T3=cut-back technique, T4=Surge technique, T5=Portable techniques, Ea (%) Application efficiency, D_U=Distribution uniformity (%) = Storage Efficiency, D_{pr}= Deep percolation ratio.

CONCLUSION

In Block A, which had a furrow length of 50 m, furrow irrigation using the surge application approach was found to be the most efficient. Its application efficiency was the highest (87%) compared to the cut-back technique (86.6%), cut-off technique (79.98%), portable structure (76.51%), and bund technique (75.00%). The bund technique had the lowest water advance and recession time. The storage requirement was highest when using surge and cut-off techniques, both of which recorded above 99%, compared to the cut-off technique (92.59%), portable structure (90.06%), and bund technique (88.97%). The surge technique enabled water circulation and slow entry into the soil. cut-back technique recorded the highest distribution efficiency (88.18%), while surge technique had distribution uniformity and absolute distribution efficiency of 84.01% and 82.00%, respectively. In cut-back technique, distribution uniformity and absolute distribution efficiency were 77.95% and 75.00%, respectively.

In Block B, which had a furrow length of 100 m, the surge technique recorded the highest application efficiency (66.00%), while the bund technique had the lowest efficiency (60%). cut-back and cut-off techniques also had relatively high application efficiency of 62.38% and 62.3%, respectively. Water circulation and slow entry into the soil also occurred with the surge technique. The highest storage efficiency was recorded in the surge and cut-off techniques (99.9%). The portable structure technique had the lowest storage efficiency, while the bund technique had the least storage efficiency (87.54%). Portable and cut-off techniques had relatively high distribution efficiency of 54.45% and 53.00%, respectively. However, the bund technique had the lowest distribution efficiency (52.00%), while the surge technique recorded the least distribution efficiency (51.00%). In cut-back technique, distribution uniformities were recorded at 57.89% and 57.00%. cut-off and bund techniques had distribution uniformities of 56.44% and 39.00%, respectively. The absolute distribution efficiency of cut-off and bund were 55% and 35.09%, respectively.

Using SAS software packages, the analysis showed that the surge technique had the highest mean application efficiency of 75.69%, while the bund technique had the lowest application efficiency of 70.0%. The use of the surge technique reduced irrigation water loss from 30.0% to 24.31% compared to the local bund technique. This was due to the temporary accumulation of water at the beginning of the field, which allowed reducing the entire plot flood and deep percolation water loss. The surge technique also performed better in terms of advance rate, moisture content, and application and distribution efficiencies. The surge technique had the highest mean distribution uniformity of 68.07%, while the bund technique had the lowest distribution uniformity of 58.32%.

RECOMMENDATION

The study has resulted in several recommendations to improve the field application efficiency of the irrigation scheme. Firstly, irrigation water users can opt for either a surge or cut-back water application approach to achieve better application and distribution efficiencies, particularly under conditions similar to those in the study area. However, additional experiments should be conducted with various field water management techniques, repeated over seasons and locations, to draw more reliable recommendations. Secondly, simple and inexpensive equipment should be developed to schedule irrigation water through surge or cut-back systems. Thirdly, a real-time mathematical model that relates various factors to water application and distribution efficiencies can be a useful tool for applying the surge concept under different field conditions. Lastly, this study could be applied in the Ethiopia Sugarcane Project, which is plagued by problems such as deep percolation, tail-water run-off, entire plot flood, and low irrigation efficiency.

REFERENCES

Abdel, D. A. M., & Adeeb, W. A. M. (2014). Comparison between hydro-flume and open field head ditch irrigation systems at Kenana Sugar Scheme, Sudan. *Agricultural Sciences*, *5*(7), 588-603. http://dx.doi.org/10.4236/as.2014.57062

Abdelmoneim, E. M., Abdelrhman, M. N., Mohmed, A., Nahla, O. A., (2019). Effect of Different Irrigation Techniques, Soil Depth, Location along the Furrow and Furrow end Condition on Soil Moisture Content. *Agricultural and Biological Sciences Journal, 5*(3), 88-97.

Abdulkadir, A., Wuddivira, M. N., Abdu, N., & Mudiare, O. J. (2011). Use of Horton infiltration model in estimating infiltration characteristics of an alfisol in the Northern Guinea Savanna of Nigeria. *Journal of Agricultural Science and Technology*, *A1*, 925-931.

Awulachew, S. B., & Ayana, M. (2011). Performance of irrigation: An assessment at different scales in Ethiopia. *Experimental agriculture*, *47*(S1), 57-69. https://doi.org/10.1017/S0014479710000955

Burt, C. M., Clemmens, A. J., Strelkoff, T. S., Solomon, K. H., Bliesner, R. D., Hardy, L. A., Howell, T. A., Eisenhauer, D. E. (1997). *Irrigation performance measures efficiency and uniformity.* Journal of Irrigation and Drainage Engineering, 123(6), 423–442. https://doi.org/10.1061/(ASCE)0733-9437(1997)123:6(423)

Dejen, Z. A. (2015). *Hydraulic and operational performance of irrigation schemes in view of water saving and sustainability: sugar estates and community managed schemes In Ethiopia*. Wageningen University and Research. https://edepot.wur.nl/328862

Eldeiry, A. A., Garcia, L. A., El-Zaher, A. S. A., & Kiwan, M. E. S. (2005). Furrow irrigation system design for clay soils in arid regions. *Applied engineering in agriculture*, *21*(3), 411-420. https://doi.org/10.13031/2013.18460

Elsheikh, M. A. E., Mohamed, A. E., and Salih, S. A. R. (2014). *Effects of some techniques on long furrow efficiency.* BSc. Thesis, Department of Agricultural Engineering, University of Neelain.

Evans, R. G., Girgin, B. N., Chenoweth, J. F., & Kroeger, M. W. (1995). Surge irrigation with residues to reduce soil erosion. *Agricultural water management*, *27*(3-4), 283-297. https://doi.org/10.1016/0378-3774(95)01151-8

Hamdy, A., Ragab, R., & Scarascia-Mugnozza, E. (2003). Coping with water scarcity: water saving and increasing water productivity. *Irrigation and Drainage: The Journal of the International Commission on Irrigation and Drainage*, *52*(1), 3-20. https://doi.org/10.1002/ird.73

Humpherys, A. S. (1968). Automatic Irrigation. https://eprints.nwisrl.ars.usda.gov/id/eprint/1100/1/131.pdf

Humpherys, A. S. (1989). Surge irrigation: 1. An overview. *ICID Bulletin*, *38*(2), 35-48. https://eprints.nwisrl.ars.usda.gov/id/eprint/533/1/709.pdf

Irmak, S., Odhiambo, L. O., Kranz, W. L., & Eisenhauer, D. E. (2011). *Irrigation efficiency and uniformity, and crop water use efficiency.* Biological Systems Engineering: Papers and Publications. https://extensionpublications.unl.edu/assets/pdf/ec732.pdf

Issaka, R. Z., Ibrahim, H., & Issah, M. H. (2015). Performance evaluation of furrow lengths and field application techniques. *International Journal of Scientific & Technology Research*, *4*(10), 278-281. https://www.ijstr.org/final-print/oct2015/Performance-Evaluation-Of-Furrow-Lengths-And-Field-Application-Techniques.pdf

Jurriëns, M., Zerihun, D., Boonstra, J., & Feyen, J. (2001). *SURDEV: surface irrigation software; design, operation, and evaluation of basin, border, and furrow irrigation* (No. 59). International institute for land reclamation and improvement/ILRI. http://library.wur.nl/WebQuery/wurpubs/fulltext/149439

Kostiakov, A. N. (1932). On the dynamics of the coefficient of water-percolation in soils and on the necessity of studying it from a dynamic point of view for purposes of amelioration. *Trans. 6th Cong. International. Soil Science, Russian Part A*, 17-21.

Mojira, T., & Dagalo, S. (2021). Evaluation of Hydraulic Performance of Irrigation Scheme at Kuraz Sugar Development Project, Jinka, Ethiopia. *American Journal of Mechanics and Applications, 9*(2), 18-29. https://doi.org/10.11648/j.ajma.20210902.12

Ogbolumani, O. A., & Nwulu, N. I. (2022). A food-energy-water nexus meta-model for food and energy security. *Sustainable Production and Consumption*, *30*, 438-453. https://doi.org/10.1016/j.spc.2021.12.019

Salih, S. A. R. (2014). *Effect of some techniques on long furrow irrigation efficiency.* https://doi.org/10.15242/IICBE.C0314187

Shaikh, I. A., Wayayok, A., Abdullah, A. F. B., Soomro, A. M., & Mangrio, M. (2015). Assessment of water application losses through irrigation surveys: A case study of Mirpurkhas Subdivision, Jamrao Irrigation Scheme, Sindh, Pakistan. *Indian J. Sci. Tech*, *8*(11), 1-15. https://doi.org/10.17485/ijst/2015/v8i11/54103

Shen, J. (1981). *Discharge characteristics of triangular-notch thin-plate weirs* (No. 1617). United States Department of the Interior, Geological Survey. https://doi.org/10.3133/wsp1617B

Singh, P., & Chauhan, H. S. (1973). Determination of water intake rate from rate of advance. *Transactions of the ASAE*, *16*(6), 1081-1084. https://doi.org/10.13031/2013.37701