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Effect of Different Irrigation Techniques, Soil Depth, Location Along the Furrow and Furrow end Condition on Soil Moisture Content

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Abstract

The study was conducted to determine the soil moisture content down the profile and along the furrow run. In addition to evaluate the furrow irrigation under four irrigation techniques (surge flow, bunds, cut-back and cut-off). The techniques were applied on free end furrows and dyked end furrows. The results indicated that, irrigation techniques, soil depths, locations along the furrow and their interactions were found to have highly significant effects on soil moisture content on depth basis at ($P \leq 0.01$). Whereas, the interaction of soil depth and furrow end conditions had no significant effects on soil moisture content. Surge technique resulted in significantly high moisture content at the two furrow end conditions, followed by bund, cut-back and cut-off technique. The results also showed that the highest application efficiency of 60.29% was obtained with surge irrigation technique with dyked furrow end (at $P \leq 0.05$) and the lowest application efficiency of 29.21% was obtained by cut-off irrigation technique with free end furrow. Surge technique resulted with highest values in all tested efficiencies within the dyked end and free end furrows compared to all other combinations.

Keywords

Irrigation Techniques, Soil Depth, Moisture Content, Furrow End, Cut-back

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1. Introduction

Furrow irrigation is suited for clean tilled crops that can be planted in rows [1]. Application of water in furrows able to avoid flooding the entire field surface by channeling the flow along the primary direction of the field slope [2]. There are many techniques which can be used to increase furrow irrigation efficiencies [3]. These techniques include bunds (strips) along the run, the traditional method cut-off, cut-back method and surge flow. Those techniques are usually used to improve the effectiveness of irrigation and to decrease the surface losses such as runoff and deep percolation. Bunds are strips made along the run or along the furrow so as to increase the duration between applying the water and infiltration i.e. to increase the contact time or opportunity time. These bunds can be made of earth 15cm high from the bottom of the furrow or made of grass so as to slow the flow for a time for more water to infiltrate. Contour bunding is most widely practiced in semi-arid tropics. The conventional contour bund system allows water to stagnate for long period in extensive areas along the bunds that affect crop yields in these areas. Conventional contour bunding involves the construction of small bunds across the slope of the land along the run so that the slope is reduced in series of small ones. Each contour bund is provided with an elevated spillway at the lower end of the field. Each contour bund acts as a barrier

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to the flowing water to concentrate in an area, thereby allowing more water to be absorbed into the soil profile. The conventional design allows a considerable volume of runoff to be impounded near the bund [2]. In many countries, the name bund is associated with various kinds of erosion-controlling banks, which have grass or shrubs planted on them. The object of the grass maybe whether to trap silt from surface runoff water or for the roots to help bind the banks together [4].

Cutoff is the traditional practice to stop the flow when the advancing wetting from reached 75% of the furrow length. The test of the traditional practice was conducted using flow rate 1.5 times or more than the flow rate used with cut-back method, when the advance wetting front of the flow reached the end of the furrow, the flow was completely cutoff. For the cut-back method of efficient surface irrigation the minimum deep percolation and runoff need to be maintained. However, in most furrow irrigation with a little or no runoff the large deep percolation resulted. On the other hand, when a high distribution efficiency is achieved, considerable surface runoff results.

Huge efforts have been done in the concept of quarter rule in order to minimize deep percolation losses on the upper end of the furrow [5]. Based on this concept, water should reach the lower end in one-fourth of the time required for the desired depth of water to infiltrate in the soil. This concept may be achieved by changing the inflow rate and/or the length of run [6]. One method of minimizing tail water is to reduce the furrow inflow when the advance phase is completed. Most cut-back systems are designed to operate in two concurrent sets, on advance phases set and on wetting or ponding set, the advance and wetting phases are both equal in duration to the required intake opportunity time [2].

The limit of the size for furrow stream may be carrying the capacity of the furrow. Because the intake rate decreases with time and some ponding occurs in the furrow, it is usually better to "cut-back" the furrow stream after it has reached the end of the furrow. Cut-back may not be necessary where grades are nearly flat and furrows have adequate storage capacity [5]. Cut-back irrigation increases application efficiency by reducing runoff losses. The use of this practice allows larger stream sizes and deep percolation losses. Cut-back is commonly used to reduce the quantity of irrigation runoff. This method utilizes a large furrow stream to rapidly advance the length of the field and wet up the furrow. When the water has reached the end of the field, the size of furrow stream is cut-back to one third or to one half of the original furrow flow. Cut-back can reach application efficiency of 80% or more and results in only 10-15% of the total applied water as runoff. The desirable operational practice is to cut-back the initial stream size appreciably after it has reached the lower end when enough water is running off to justify the effort. The time of cut-back should be such that fairly large stream running off at that moment should be about the same size as will be running off at the end of irrigation after having been cut-back.

Surge flow is a relatively new procedure for automating surface irrigation systems in which problems with slow advance and excessive surface runoff occur [7]. It has been defined as the intermittent application of irrigation water to furrows or border, creating a series of on and off modes of constant or variable time spans [8]. It is accomplished by alternating furrows with rest periods of zero inflow. The duration of time between successive inflow periods called the cycle time, is chosen so that several on off cycles are required to complete the advance phase of the irrigation. During the advance phase the duration of rest periods is normally long enough for most, if not all, water to infiltrate before the next inflow period begins. The ratio of on to off times is cycle ratio. Although, the cycle time varies during the irrigation, the cycle ratio must remain constant, i.e. the on time equals to the off time [7]. Each surge is characterized by a cycle time and cycle ratio [2]. The cycle time ranges from one minute to as much as several hours. Cycle ratio typically ranges from 0.25 to 0.7. By regulation of these two parameters, surge flow can improve irrigation efficiency and uniformity. Surge flow irrigation has higher efficiency and is more capable of automation compared to conventional methods [9]. By reducing the volume of water required to complete an advance the surge irrigation technique gives the potential to increase the distribution uniformity and hence, increase the effective use of water in furrow irrigation [2, 8-12]. Increasing of the rapid advance improves the uniformity of the irrigation and allows higher application efficiency to be achieved [7]. Proper management is required to reduce deep percolation and run off losses and to achieve higher application efficiencies. Uniform water distribution over the furrow length was obtained by overlapping surges. Deep percolation losses decreased from 12-15% to 6-8% while run off losses were reduced from 25-30% to 12% when using surge irrigation. Surge irrigation requires 20-25% less water than continuous irrigation.

Water application efficiency is the volume of water needed and made available for evapotranspiration by the crop to avoid undesirable water stress in the plants through the growing cycle divided by the volume of water delivered to the field [13].

Water storage efficiency becomes important when water supplies are limited, also when salt problems exist. The water storage efficiency should be kept high to maintain a favorable salt balance [14]. Therefore, the objectives of the study were: 1) to evaluate furrow irrigation performance under four irrigation techniques including surge, bund, cut-back and cut-off; 2) to improve the efficiencies of furrow irrigation by using the appropriate technique.

2. Materials and Methods

The experimental work was conducted at the Top and Demonstration Farms of the University of Khartoum latitude 15°40′N and longitude 32°32′E. The climate is described as tropical arid .Soil mechanical analysis was conducted at the Soil Science Laboratory of the Faculty of Agriculture, University of Khartoum. Samples were taken from three locations chosen randomly in the field. From each location four samples were taken at depths of 0.2, 0.4, 0.6 and 0.8m down the soil profile. Mean for each depth was taken to represent the soil textural class .The first experimental period extended from November 1997 to January 1998, the second period from April to June 1998 and the last from October to November 1998. The four techniques used were surge, bund, cut-back and cut-off. At the Top Farm the four techniques were applied on open ended furrows and dyked end furrows as main plots. The furrow length was 190m and 0.8m wide. The total area of the experimental work was 3900m^2. While the Demonstration Farm was 82m and 0.8m with total area of 1700m^2. The experimental design followed was the split plot design with three replicates. Heads of 0.25m were maintained in the stabilizer ditch (a ditch running parallel to the head ditch). Stream of mean value of 3L/s was turned into each furrow using two calibrated syphon tubes with 0.05m inside diameter and 2.8m long of discharge of 1.5L/s was obtained as a furrow stream to apply water. Land preparation was carried out with disc plough (to a depth of 0.25m), disc harrow to break the clods, and firm the top soil, leveler, land surveying and land ridging.

Land preparation

The land preparation of the experimental area:

1. Disc ploughing to a depth of about 0.25m with standard integral disc plough.
2. Disc harrowing was performed with an offset disc Harrow to break the clods and firm the top soil.
3. Levelling as done by along span blade leveler.
4. Land surveying was conducted with grid spacing of 5m. The elevations of the grid points were determined with dumpy level and level rod. The first reading was made on a Benchmark (BM) which was assumed to be of l0m height. Based on the rod readings, the reduced levels were computed.
5. Ridging was done with three ridger bottoms, which were mounted on a tool bar to give standard ridge spacing of about 0.8m. The head ditch was excavated at the upper part of the field in order to facilitate the control and measurement of the inflow rate.

Soil Mechanical and Physical Properties

Soil mechanical analysis was conducted at the soil science laboratory of the Faculty of Agriculture, University of Khartoum.

Soil Textural Class

Soil class was determined using the hydrometer method [15]. Samples were taken from three locations spreaded randomly over the field. From each location four samples were taken at depths of 0.2, 0.4, 0.6 and 0.8m below the soil surface. A mean for depths was taken to represent the soil class.

Soil Moisture Determination

Soil water was determined gravimetrically. Soil samples were augered from successive stations along the furrows. The soil samples were taken at 0.2m increments from the soil surface to depth of 0.8m before and three days after each irrigation. Samples were oven dried at 105-110°C for 24 hours, then weighted to determine moisture content as percentage on dry mass basis (Equation 1).

$$\theta m\% = \frac{Mw - Md}{Md} * 100 \tag{1}$$

Where: m% = Moisture content on mass basis as percent Mw = Mass of wet sample (gm). Md = Mass of oven dry sample (gm) To convert moisture content on dry mass basis as percentage to moisture content on volume basis as percentage and depth basis (cm/m depth) the corresponding bulk density (Equation 2) was multiplied by moisture content on mass basis.

$$\theta v\% = \theta m\% * pb \tag{2}$$

$$\theta v\% = \theta d\%(cm / m)depth$$

Where: v% = moisture content on volume basis as percent. pb = bulk density (gm/cm^3) d = moisture content cm per m depth of soil.

Measurement of the Irrigation Stream

The furrows were irrigated from a stabilizer ditch using syphon tubes. The syphon tubes were calibrated in situ to estimate their discharge per unit time and to select the suitable irrigation stream size. Using the selected irrigation water was applied to each furrow.

i. Calibration of Syphon Tubes

Syphon tubes 0.06m in diameter and 2.8m long were used in this experiment. The discharge of the syphon tubes in lit/sec was obtained in the field at different water heads in the stabilizer ditch. The calibration was done as follows:

A hole was dug adjacent to the stabilizer ditch and a bucket of known volume was installed in it. The rim of the bucket was kept with the soil surface. The Syphon tube was primed and directed into the bucket where it discharge. By using stop watch the time required to fill the bucket was recorded. The discharge of the syphon tube in lit/sec was calculated using the following equation 3:

$$Q = \frac{V}{T} \tag{3}$$

Where: Q = discharge (lit/sec) V = volume of water (lit) T = time required to fill the bucket (sec) For each head three readings were made and their mean was taken to represent the discharge per unit time for that particular head.

ii. Irrigation Stream

Heads of 0.25m for the short and 0.3m for the long furrows were maintained, respectively, in the stabilizer ditch. At the head of 0.25m at the stabilizer ditch, discharge of 1.5lit/sec was obtained as a furrow stream to apply water to the short furrow. And at a head of 0.3m in the stabilizer ditch a discharge of 1.7lit/sec was taken as a furrow stream to apply water to the long furrow.

The depth of irrigation water applied was calculated using the following equation 4.

$$d = \frac{Q * t1000 * 60}{w * I100 * 100} \tag{4}$$

Where:

d = depth of water applied (cm)

Q = discharge (lit/sec)

t = irrigation period (min)

W = furrow width (m)

I = furrow length (m)

3. Results and Discussion

Soil Textural Class

Table 1 (a and b) shows the percentage particle size distribution obtained for increments of 0.2m down the soil profile to 0.8m depth for two sites. According to USDA soil textural classification chart, the soil was classified as clay for both experimental sites. There were no significant differences between the four incremental depths for the clay, silt and sand percentages for the two sites, but clay percentage increased with depth. Whereas silt percentage decreased with depth, while sand percentage remained relatively constant. This agreed with results obtained in previous publications [16, 17].

Table 1. Soil particle size distribution for each 0.2m from the surface to 0.8 depth in two sites (a = demonstration farm and b = top farm).

a/Demonstration Farm

Depth (m)	Clay (%)	Silt (%)	Sand (%)	Class
0.0 – 0.2	45.28	31.32	23.4	Clay
0.2 – 0.4	48.43	29.11	22.43	Clay
0.4 – 0.6	49.65	32.25	18.10	Clay
0.6 – 0.8	50.00	31.34	16.0	Clay

b/Top Farm

Depth (m)	Clay (%)	Silt (%)	Sand (%)	Class
0.0 – 0.2	47	24.67	25.33	Clay
0.2 – 0.4	51	22.11	26.89	Clay
0.4 – 0.6	49	22.45	28.55	Clay
0.6 – 0.8	54	21.67	24.33	Clay

Effect of the Different Irrigation Techniques on Soil Moisture Content on Depth Basis (cm/m depth)

The effects of the irrigation techniques location relative to the upper end of furrow, soil depth, nature of the furrow end and their interactions on soil moisture content on depth basis (cm/m) were investigated in the following sections.

3.1. Effect of Irrigation Technique and Distance from the Upper End of the Furrow on Soil Moisture Content

Results of soil moisture content as affected by irrigation technique are presented in Table 2 (a and b). Irrigation technique distance from upper end of the furrow and their interaction were found to have high significant effects on moisture content on depth basis at both experimental sites ($P \leq 0.01$).

Irrigation techniques were significantly different as far as moisture content on depth basis was concerned. Surge irrigation technique resulted in the highest moisture content of 31.12 and 38.57cm/m for the Demonstration and Top Farms, respectively.

While cut-off irrigation technique resulted in the lowest moisture content of 22.91 and 30.87cm/m for the two sites of experiment. These results can 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.

Different locations along the furrow had significant means as shown in Table 2 (a and b). 10 m from the upper end of the furrow had the highest moisture content of the 27.99cm/m and 36.98cm/m depth for the Demonstration and the Top farm, respectively, followed by the location at 41m from the upper end which recorded 27.14cm/m, and at 72m which recorded 25.88cm/m of moisture content for the Demonstration Farm. However, for the Top Farm the moisture content showed the same relationship with distance from furrow upper stream end with 10m recording 36.98cm/m followed by 95m, which recorded 34.47cm/m, and 180m that recorded 29.96cm/m.

The interaction between irrigation technique and location from upper end of the furrow were significant as for as moisture content values depths were concerned. Surge irrigation technique at 10m from the upper end of the furrow had the highest moisture content of 32.49cm/m and 40.83cm/m at the Demonstration and the Top Farm, respectively. The lowest mean moisture content values on depth basis at the Demonstration Farm were 22.43 and 22.09cm/m at 41m and 72m from the upper and end of the furrow, respectively with cut-off irrigation technique. Also cut-off technique gave the lowest mean of 26.32cm/m at 180m from the upper end of the furrow at the Top Farm.

Table 2. Effect of irrigation technique on soil moisture content at different locations along the furrow.

a/Demonstration Farm

Location (m)	Soil Moisture Content (cm/m depth)				Mean
	Irrigation Technique				
	Surge	Bund	Cut - back	Cut - off	
10	32.49 a	28.48 d	26.78 e	24.21 g	27.99 a
41	31.60 b	28.80d	25.73 f	22.43 h	27.14 b
72	29.28 c	27.34 e	24.78 g	22.09 h	25.88 c
Mean of technique	31.12 a	28.21 b	25.77 c	22.91 d	

SE of technique, location and interaction were 0.18, 0.15 and 0.30.

b/Top Farm

Location (m)	Soil Moisture Content (cm/m depth)				Mean
	Irrigation Technique				
	Surge	Bund	Cut- back	Cut -off	
10	40.83 a	37.12c	36.04 d	33.91 e	36.98 a
95	39.42 b	33.37 ef	32.70 fg	32.38 g	34.47 b
180	35.54d	29.65 h	28.41 i	26.32 j	29.96 c
Mean of technique	38.57 a	33.38 b	32.38 c	30.87 d	

SE of technique, location and interaction were 0.21, 0.15 and 0.30. Means followed with similar letters is not significantly different from each other at 0.05 level of probability according to DMRT.

3.2. Effect of Irrigation Technique on Soil Moisture Content down the Profile

The effect of irrigation techniques on soil moisture content down the profile is shown in Table 3 (a and b). Irrigation technique, soil depth and their interaction showed high significant effects on soil moisture content at both experimental sites ($P \leq 0.01$). Depth of 0.2m had the highest mean moisture content of 31.19cm/m compared to all other depth at the Demonstration Farm.

Whereas 0.4m soil depth had recorded the highest mean moisture content when compared to 0.6m and 0.8m soil depth which were not significantly different from each other at ($P \leq 0.05$). While at the Top Farm 0.8m soil depth had the highest mean moisture content of 35.63cm/m followed by 0.6m soil depth of 34.47cm/m. Whereas the depth of 0.2m and 0.4 had significantly low values of 32.76 and 32.35cm/m, respectively, when compared to that of 0.6m depth. The interaction between irrigation technique and soil depth was significant as for as moisture content depths basis was concerned. Surge irrigation technique at 0.2m had recorded the highest value of 35.84cm/m of moisture content at the Demonstration Farm. While the lowest values of moisture content of 19.66 and 20.29cm/m were obtained at 0.6 and 0.8m soil depths, respectively with cut-off irrigation technique with no significant different between them. However at the Top Farm, surge irrigation produced the highest moisture content of 41.43cm/m at 0.8m soil depth. Whereas the lowest moisture content of 29.82cm/m was obtained with cut–off irrigation technique at 0.4m soil depth. It was observed that at the Demonstration Farm surge irrigation technique at 0.2m soil depth had significantly the lightest moisture content. Whereas at the Top Farm surge irrigation technique had the highest moisture content at 0.8m soil depth. These results can be attributed of the fact that the soil at the Demonstration Farm may be compacted and had a plough pan preventing water from entering the underneath soil layers. Similar results were obtained by Saeed [17].

Table 3. Soil moisture content (cm/m depth) for the different soil depth and the different irrigation techniques.

a/Demonstration Farm

Irrigation Techniques	Soil Moisture Content (cm/m depth)				
	Soil depth (m)				Mean
	0.0 - 0.2	0.2 - 0.4	0.4 - 0.6	0.6 - 0.8	
Surge	35.84 a	32.86 b	28.32 cd	27.48 de	31.12 a
Bund	33.64 b	29.43 c	24.36 h	25.40 g	28.21 b
Cut-back	28.08 de	26.47 f	23.96 h	24.55 gh	25.77 c
Cut-off	27.18 ef	24.50 gh	19.66 i	20.29 i	22.91 d
Mean of depth	31.19 a	28.32 b	24.08 c	20.43 c	

SE for technique and location was 0.18, and for interaction was 0.35.

b/Top Farm

Irrigation Techniques	Soil Moisture Content (cm/m depth)				
	Soil depth (m)				Mean
	0.0 - 0.2	0.2 - 0.4	0.4 - 0.6	0.6 - 0.8	
Surge	36.24 a	37.31 c	39.29 d	41.43 a	38.57 a
Bund	33.48 ef	32.11 g	33.03 f	34.91 e	33.38 b
Cut-back	30.56 ij	30.15 ij	34.50 e	34.32 e	32.38 c
Cut-off	30.74 ij	29.82 j	31.04 hi	31.88 gh	30.87 d
Mean of depth	32.76 c	32.35 c	34.47 b	35.63 a	

SE for technique = 0.21, for location = 0.21 and for interaction = 0.35. Means followed with similar letters is not significantly different from each other at 0.05 level of probability according to DMRT.

3.3. Effect of Irrigation Technique and Furrow End Condition (Dyked or Free) on Moisture Content down the Profile

Results of soil moisture content on depth basis, as affected by irrigation technique and furrow end condition at the Top Farm are shown in Table 4. Furrow end condition had no significant effect on moisture content ($P \leq 0.05$) down the profile. This can be attributed to the longer time spent by water on the furrow before recession. The interaction between irrigation technique and furrow end condition had significant effect on moisture content at different depths.

Surge irrigation technique in dyked end furrow produced the highest value of moisture content of 39.75cm/m on depth basis compared to the other combination. However cut-back technique in dyked end furrow were not significantly different from each other. Also bund and cut-back techniques, both in free end furrow were statistically similar in terms of soil moisture content. This might be due to the fact that using cut-back technique resulted in declined water advance rate, so water stayed for a long time on the soil surface. Similarly, in the case of bunds there was a better opportunity for water to enter [2]. Whereas, the lowest moisture content of 30.7cm/m was obtained with cut-off irrigation technique in dyked end furrows. A value, which was not significantly different from that obtained under cut-off technique in free end and cut-back in dyked end furrows which recorded 31.04 and 31.84cm/m, respectively. This can be attributed to the fact that cut-off and cut-back techniques had the same opportunity time allowing the same amount of water to enter the soil when the furrow end was dyked.

Table 4. Effect of Irrigation technique and end condition on moisture content (cm/m depth) at the Top Farm.

Irrigation Techniques	Soil Moisture Content (cm/m depth)		
	Furrow end condition		Mean
	Dyked	Free end	
Surge	39.75 a	37.36 b	38.57 a
Bund	33.86 c	32.90 cd	33.38 b
Cut-back	31.84 f	32.92 cd	32.38 c
Cut-off	30.70 f	31.04 f	30.87 d
Mean of end	34.04 a	33.56 a	

SE for technique, furrow and interaction were 0.21, 0.12 and 0.25. Means followed with similar letters is not significantly different from each other at 0.05 level of probability according to DMRT.

3.4. Effect of Soil Depth and Location along the Furrow on Soil Moisture Content

Table 5 (a and b) show that the interaction of soil depth and location along the furrow had high significant effects on moisture content at both experimental sites ($P \leq 0.01$). At the Demonstration Farm, the location 10m from the upper end of the furrow recorded the highest moisture content on depth basis of 32.21cm/m at 0.2 soil depth, While 72m from the upper end of the furrow recorded the lowest values of 23.45cm/m and 23.44cm/m of moisture content at 0.6 and 0.8 in down of the profile, respectively. However, at the Top Farm 0.6m and 0.8m soil depths had the highest values of 38.33 and 38.61cm/m of moisture content at 10m from the upper end of the furrow, respectively. Whereas, the lowest value of 28.61cm/m of moisture content was recorded at 180m from the upper end of furrow at 0.4 in soil depth. It is clear that the mean soil moisture content was high near the furrow upper end and it decreased with increasing distance along the furrow. This might be due to tile longer contact time at locations near the upper end of the furrow.

Table 5. Effect of soil depth and location along the furrow on soil moisture content (cm/m depth).

a/Demonstration Farm

Location (m)	**Soil Moisture Content (cm/m depth)**				**Mean**
	Soil Depth (m)				
	0.0 – 0.2	**0.2 - 0.4**	**0.4 - 0.6**	**0.6 - 0.8**	
10	32.21 a	30.15 b	24.48 de	25.12 d	27.99 a
41	31.74 a	27.81 c	24.30 ef	24.73 de	27.14 b
72	29.62 b	26.99 c	23.45 f	23.44 f	25.88 c
Mean of Depth	31.19 a	28.32 b	24.08 c	24.43 c	

SE for technique, location and interaction = 0.18, 0.15 and 0.30.

b/Top Farm

Location (m)	**Soil Moisture Content (cm/m depth)**				**Mean**
	Soil Depth (m)				
	0.0 – 0.2	**0.2 - 0.4**	**0.4 - 0.6**	**0.6 - 0.8**	
10	35.59 c	35.38c	38.33a	38.61a	36.98 a
95	32.41d	33.07d	34.97c	37.43b	34.47 b
180	39.27f	28.61g	30.11e	30.86	29.96c
Mean of Depth	32.75c	32.35c	34.47b	35.63 c	

SE for technique = 0.21, for location = 0.15 and for interaction = 0.30. Means followed with similar letters is not significantly different from each other at 0.05 level of probability according to DMRT.

3.5. Effect of Furrow End Condition and Location along the Furrow on Soil Moisture Content (cm/m (Depth)

Results of soil moisture content as affected by furrow end condition and location along the furrow at the Top Farm were presented in Table 6. The interaction of furrow end condition and location had a high significant effect on soil moisture content. All means of moisture content values were significantly different from each other due to location except at 95m from the upper end of the furrow in case of both dyked and free end furrows. This might be due to the fact that in the middle of the furrow length the furrow end condition did not affect the water amount on the soil surface. i.e. the back flow that might be caused by dyking the furrow end, did not effectively reach the middle of the furrow.

Table 6. Effect of Furrow End Condition and Location along the Furrow (m) on Soil Moisture Content (cm/m depth).

Location (m)	**Soil Moisture Content (cm/m depth)**		**Mean**
	Soil depth (m)		
	Dyked	**Free End**	
10	37.31 c	36.64 b	36.98 a
95	34.16 c	34.78 bc	34.47 b
180	30.65 d	29.27 c	29.96 c
Mean of depth	34.04 a	33.56 a	

SE for technique, location and interaction were 0.12, 0.15 and 0.21. Means followed with similar letters is not significantly different from each other at 0.05 level of probability according to DMRT.

3.6. Effect of Soil Depth and Furrow End Condition on Soil Moisture Content (cm/m Depth)

Results of moisture content as affected by the interaction were presented in (Table 7) at the Top Farm. The interaction of soil depth and furrow end condition had no significant effect on soil moisture content. However, the highest moisture content was obtained with free end furrow at 0.8m depth. While the lowest moisture content was obtained at 0.4 m soil depth with free furrow end. It was noticed that the moisture content was found to increase with depth in both types of furrow end conditions and that time dyked-end furrows always has higher moisture content values than the free end furrow, except at 0.8m soil depth. The attributes for this were stated before.

Table 7. Effect of soil depth (m) and furrow end condition on soil moisture content (cm/m depth) at the Top Farm.

Soil Depth (m)	**Soil Moisture Content (cm/m depth)**		**Mean**
	Soil Depth (m)		
	Dyked	**Free End**	
0.0 - 0.2	32.86 d	32.65 d	32.76 c
0.2 - 0.4	32.71 d	31.99 e	32.35 c
0.4 - 0.6	35.20 b	33.74 c	34.47 b
0.6 - 0.8	35.40 b	35.87 a	35.63 a
Mean of end	34.04 a	33.56 a	

SE for furrow end = 0.12, for soil depth = 0.15 and for interaction = 0.30. Means followed with similar letters is not significantly different from each other at 0.05 level of probability according to DMRT.

3.7. Effect of Irrigation Technique, Soil Depth and Furrow End Condition on Soil Moisture Content (cm/m Depth)

At the Top Farm the interaction of irrigation technique, soil depth and furrow end condition significantly ($P \leq 0.05$) affected moisture content as shown in Table 8. The highest moisture content of 42.91cm/m was obtained with surge irrigation at 0.8m depth in dyked end furrows. While the lowest moisture content values of 29.98 and 29.78cm/m were obtained at 0.2m and 0.4m soil depth, respectively with cut-off and cut-back irrigation techniques, while free end furrows with the same technique had recorded moisture content of 29.69cm/m at 0.4m soil depth.

Table 8. Effect of irrigation technique, soil depth and location along the furrow on soil moisture content.

Irrigation Techniques	**Soil Moisture Content (cm/m depth)**							
	Furrow end condition							
	Dyked				**Free end**			
	Soil depth (m)				**Soil depth (m)**			
	0.0 – 0.2	**0.2 - 0.4**	**0.4 - 0.6**	**0.6 – 0.8**	**0.0 - 0.2**	**0.2 - 04**	**0.4 - 0.6**	**0.6 - 0.8**
Surge	35.99 def	38.53 c	41.58 b	42.91 a	36.49 d	36.10 de	36.99 d	39.95 b
Bund	34.98 fg	32.53 ijk	32.86 ij	35.08 efg	31.98 jki	31.69 jki	33.19 hi	34.74 fg
Cut-back	30.48 i	29.78 m	35. 01 efj	32.10 ijk	30.64 im	30.53 i	34.00 gh	36.54 d
Cut-off	29.98 m	29.99 m	31.33 k	31.50 i	31.49 ki	29.69 m	30.77 im	32.22 ijk
Mean of depth	34.04 a				33.56 a			

SE for technique and soil depth was 0.21, and for interaction was 0.49. Means followed with similar letters is not significantly different from each other at 0.05 level of probability according to DMRT.

3.8. Effect of Irrigation Technique, soil Depth (m) and Furrow End Condition on Soil Moisture Content at Top Farm

Soil moisture content was significantly affected ($P \leq 0.05$) by the interaction of irrigation technique, soil depth and location along the furrow at the Demonstration farm as shown in Table 9 (a, b and c). Whereas, at the Top Farm this interaction had no significant effect on moisture content ($P \leq 0.05$). Surge irrigation technique at 10 m 41 m and 72m from the upper end of the furrow had recorded the highest moisture content values of 37.32cm/m, 35.98cm/m and 34.31cm/m, respectively, at 0.2m soil depth. However at 41m from the upper end of the furrow bund irrigation technique at the same soil depth of 0.2m had also recorded a value of 34.99cm/m of moisture content. Whereas 10m from the upper end of the furrow and 0.6m soil depth had recorded the lowest moisture content of 19.82cm/m when using cut-off irrigation technique. However at 41m from the upper end of the furrow cut-off irrigation technique had resulted in low values of 20.20cm/m and 19.50cm/m at 0.6 and 0.8m soil depth, respectively. Similarly 72m from the upper end of the furrow had the lowest moisture content of 18.96cm/m at 0.6m soil depth under cut-off irrigation technique.

Table 9. Effect of irrigation technique, and soil depth on soil moisture content (cm/m depth) at the Demonstration Farm.

a/10m from the upper end of the furrow

Irrigation Technique	**Soil Moisture Content (cm/m depth)**				**Mean**
	soil depth (m)				
	0.0 – 0.2	**0.2 - 0.4**	**0.4 - 0.6**	**0.6 – 0.8**	
Surge	37.32 a	34.44 b	29.41 d	28.88 de	32.49 a
Bund	33.76 b	31.07 c	23.3 ih	25.79 g	28.48 b
Cut- back	29.05 de	28.01 ef	25.38 g	24.69 gh	26.78 c
Cut -off	28.81 de	27.09 f	19.82 j	21.11 i	24.21 d
Mean of Soil Depth	32.21 a	30.15 b	24.48 c	25.12 c	

SE for technique and soil depth was 0.32, and interaction was 0.64.

b/41m from the upper end of the furrow

Irrigation Technique	**Soil Moisture Content (cm/m depth)**				**Mean**
	soil depth (m)				
	0.0 – 0.2	**0.2 - 0.4**	**0.4 - 0.6**	**0.6 – 0.8**	
Surge	35.98 a	33.13 b	29.41 c	27.89 d	31.60 a
Bund	34.99 a	29.37 c	24.59 gh	26.25 ef	28.80 b
Cut- back	29.35 c	25.32 fg	23.00 i	25.26 fg	25.73 c
Cut -off	26.63 c	23.40 hi	20.20 j	19.50 j	22.43 d
Mean of Soil Depth	31.74 a	27.81 b	24.30 c	24.73 c	

SE for technique and location was 0.30, and for interaction was 0.61.

c/72m from the upper end of the furrow

Irrigation Technique	Soil Moisture Content (cm/m depth)				Mean
	soil depth (m)				
	0.0 – 0.2	**0.2 - 0.4**	**0.4 - 0.6**	**0.6 – 0.8**	
Surge	34.31 a	31.01 b	26.14 d	25.66 d	29.28 a
Bund	32.17 b	27.86 c	25.18 de	24.15 ef	27.34 b
Cut- back	25.86 d	26.08 d	23.50 f	23.69 f	24.78 c
Cut -off	26.12 d	23.00 if	18.96 h	20.25 g	22.09 d
Mean of Soil Depth	29.62 a	26.99 b	23.45 c	23.44 c	

SE for technique and soil depth = 0.30, and interaction = 0.61. Means followed with similar letters is not significantly different from each other at 0.05 level of probability according to DMRT.

3.9. Effect of Irrigation Technique. Furrow End Condition and Location along the Furrow on Soil Moisture Content

The furrow end effect was studied at the Top Farm only. The interaction of irrigation technique, furrow end condition and location along the furrow had a significant effect on soil moisture content ($P \leq 0.05$) as shown in Table 10. Surge irrigation technique at 10m from the upper end of the furrow had recorded the highest moisture content of 42.28cm/m incase of dyked end furrows. However at 180m from the upper end of the furrow with cut-off irrigation technique the lowest moisture content of 25.26cm/m was obtained incase of the free end furrows. The combination, which had resulted in the highest moisture content value was surge irrigation technique at 10m from the upper end of dyked end furrow. This might be due to the greater opportunity time, high water level and longer time of wetness, also the rate of advance of water along the furrow increases in surge flow irrigation due to the reduction in the intake rate of the soil, leading to increased irrigation uniformity [18].

Table 10. Effect of irrigation technique, furrow end condition and location along the furrow at the Top Farm on soil moisture content (cm/m depth).

Irrigation Technique	Soil Moisture Content (cm/m depth)					
	Furrow end Condition					
	Dyked end			Free end		
	Location from furrow upper end					
	10 m	**95 m**	**180 m**	**10 m**	**95 m**	**180 m**
Surge	42.28a	40.57b	36.41d	39.38c	38.28cd	34.40 fg
Bund	37.92d	33.17 gh	30.50 i	36.32e	33.58gh	28.81ij
Cut- back	25.93 e	31.31li	28.29jk	36.16e	34.09 fg	28.54j
Cut -off	33.13h	31.61i	27.38k	34.70f	33.15h	25.26 i
Mean of Soil Depth	34.04a			33.56b		

SE for technique, furrow end and interaction were 0.21, 0.12 and 0.43. Means followed with similar letters is not significantly different from each other at 0.05 level of probability according to DMRT.

3.10. Effect of Soil Depth, Furrow End Condition and Location Along the Furrow on Soil Moisture Content

Moisture content was significantly ($P \leq 0.05$) affected by the interaction of soil depth, furrow end condition and location along the furrow at the Top Farm as shown in Table 11. The highest moisture content values of 39.77 and 39.52cm/m were recorded at 0.6m soil depth with dyked end furrows and 0.8m with free end furrows, respectively at 10m from the upper end. However at 0.4m soil depth free end furrow had recorded the lowest moisture content of 27.38cm/m at 180m from the upper end of the furrow. It is clear that moisture content decreased with increasing distance from the up stream furrow end allowing water to escape at the field lower end especially in the case of cut-off irrigation technique, because flow was stopped when the water front reached the lower end of the furrow. So with free end furrows water loss as run-off resulted in low amount of water being stored in the root zone.

Table 11. Effect of soil depth (m), furrow end condition and location along the furrow on soil moisture content (cm/m depth) at Top Farm.

Soil depth (m)	Soil Moisture Content (cm/m depth)					
	Furrow end condition					
	Dyked end			Free end		
	location from furrow upper end					
	10 m	**95 m**	**180 m**	**10 m**	**95 m**	**180 m**
0.0- 0.2	36.14 cd	32.00 gh	30.43 ij	30.03 de	32.83 fg	30.10 j
0.2- 0.4	35.63 d	32.65 fg	29.84 jk	35.12 de	33.49 f	27.38 l
04- 0.6	39.77 a	34.78 e	31. 04 hi	36.89 dc	35.15 d	29.17 k

Soil depth (m)	**Soil Moisture Content (cm/m depth)**					
	Furrow end condition					
	Dyked end			**Free end**		
	location from furrow upper end					
	10 m	**95 m**	**180 m**	**10 m**	**95 m**	**180 m**
0.6- 0.8	37.71 b	37.22 b	31.25 hi	39.52 a	37.63 b	30.45 ij
Mean of End	34.04 a			33.56 b		

SE of location, furrow end, soil depth and interaction were 0.15, 0.12, 0.21 and 0.43. Means followed with similar letters is not significantly different from each other at 0.05 level of probability according to DMRT.

4. Conclusions

Four furrow irrigation techniques namely; surge flow, bunds, cut-back and cut-off were applied on free end furrows and dyked end furrow conditions in order to determine the soil moisture content down the profile and along the furrow. The results indicated that, irrigation techniques, soil depths, locations along the furrow and their interactions were found to have highly significant effects on soil moisture content. Moisture content had a highly significant value near the upper end of the furrow, and decreased with increasing distance along the furrow at the two sites.

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