Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 04, April-2016

Effect of Furrow Length and Flow Rate on Irrigation Performances and Yield of Maize

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Abstract: **Furrow irrigation is the most widely practiced form of surface irrigation in the central valley of Ethiopia for cultivating different crops. This study was undertaken at Melkassa Agricultural Research Center to assess the effect of furrow length and flow rate on irrigation performance and maize yield using Melkassa II maize variety as a test crop. The experiment was designed in split plot with three replications, where furrow length used as the main plot and flow rate as sub-plot. The treatment includes furrow length of 16m, 32m, and 48m and flow rates of 0.52l/s, 0.79l/s, and 1.05l/s. The ranges of mean yield gained from furrow length and flow rate were 5.66 to 5.81ton/ha and 4.98 to 6.8ton/ha respectively. 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). The maximum yield was obtained from L_3Q_2(6.85ton/ha) but the minimum yield gained at L_3Q_2(4.85ton/ha). The range of mean crop water use efficiency from furrow length and flow rate was 8.30 to 8.53Kg/ha-mm and 7.3 to 9.98g/ha-mm respectively. The effect of furrow length on CWUE was not significant (P=0.01) but the flow rate has significant effect on yield and CWUE (P<0.01). The maximum and minimum CWUE was attained at L_3Q_2(10.02 Kg/ha-mm) and L_3Q_2(7.12 Kg/ha-mm) respectively. The highest and lowest measured values of Ea, DPR, SRR, Es, and DU range was 21.85 to 38.52%, 8.15 to 17.16%, 51.1 to 70.0%, 31.65 to 56.0%, and 29.67 to 78.3%, respectively. The irrigation performance indicators were significantly affected by both furrow length and flow rate. In a soil that has loam texture, 0.5% furrow bed slope, and a furrow length of 48m it is suitable to use 0.79l/s of flow rate for better maize yield, water use efficiency, and irrigation efficiency. 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.**

Key words: Furrow length, Flow rate, Irrigation Efficiency, Maize

I INTRODUCTION

Agricultural development is the main important sector for Ethiopian economy. The agricultural production and its impact on the Ethiopia's economy are closely linked with the occurrence and level of precipitation fluctuations [3]. For several years, the country has been facing drought. The government of Ethiopia has increased its emphasis on irrigated agriculture to mitigate the outcome of rainfall variability and to boost crop production [14].

The country is gifted with abundant renewable annual surface and ground water resources. The irrigation potential of the country is estimated about 4.3Mha [18]. Report from [14] indicated that only 10% to 12% of the irrigation potential areas are developed with irrigation which shown the untouched irrigation potential of the country. The contribution of irrigated agriculture was limited to 9.0% to the agricultural GDP and 3.7% for the overall GDP for the year of 2009/10 [5].

Bringing the irrigation potential lands of arid, semi-arid and sub-humid areas in to cultivation will increase the number of cropping season and crop production that enables to raise the national economic development and improve livelihoods.

The irrigation structures constructed across the country were not working with their intended capacity due to design problems and poor water management [1]. The expansion of irrigation without proper irrigation water management might not be a guarantee to fulfill the demand of crop production. In addition to structural concerns, it is essential to focus on improvement of irrigation water management for enhanced water productivity.

Improvement of water productivity in furrow irrigation can be achieved by applying the required amount of crop water at the right time. This includes proper design of furrow length, flow rate and irrigation period [12]. However, these parameters are not well practiced in the study area. Due to the fragmented sizes of farmers' land, the lengths of furrows are mainly less than fifty (50) meter. The possibility of using optimum or longer furrow length in the farmers is very low. Blocked furrow ends are used on sloping fields in order to prevent tail water loss but it has been resulting non uniform water distribution and heavy deep percolation at end part of furrow. Suitable flow rates are not yet identified instead any flow rate that has come to furrow is directly applied without measurement. Consequently, the practice reduces crop yield; losses irrigation water that may possible have the capacity to

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 04, April-2016

increase the cultivable land; and presence of competitions among different agricultural and non- agricultural demands.

This study was carried out to evaluate the combined effect of short open ended furrow length and flow rate on the irrigation performance and grain yield of maize at the field condition. Hence, efficient use of irrigation water might be attained for better crop production while conserving soil and water resource.

II MATERIALS AND METHODS

2.1 Site Description

The study was conducted at Melkassa Agricultural Research Center, which is found near Awash Melkassa town located at 8.4^0 N Latitude, 39.4^0 E Longitude and 107 Km far from Addis Ababa. The study area has an altitude of 1550masl with mean annual rainfall of 826.2 mm and classified under semi-arid region [13]. The mean monthly maximum and minimum temperature was 28.6 ^{0}C and 13.8 ^{0}C respectively. The dominant soil types in the center are loam and clay loam textured soil. Furrow irrigation is widely used method for applying irrigation and the source of irrigation water is Awash River.

2.2 Experimental Design

The treatments include two factors namely furrow length and flow rate. The levels of treatments include three rates of both furrow length and flow rate. The furrow length was 16m, 32m, and 48m. The flow rates were made by rating 50%, 75%, and 100% of the maximum non-erosive flow rate. The maximum non-erosive flow rate was estimated by [6].

$Q=\alpha / S^{\beta}$ ……………………..…………(1)

Where

Q = Maximum flow rate, l/s

S = Furrow slope, %

α and β are coefficient of parameters

Table2.1 Coefficient parameters for furrow maximum flow rate

Soil group	α	β
Heavy texture	0.892	0.937
Medium-heavy texture	0.988	0.550
Medium texture	0.613	0.733
Light texture	1.111	0.615
Very light texture	0.665	0.548

The field had an average furrow bed slope of 0.5% and medium textured soil. The maximum non-erosive flow rate was estimated as 1.05l/s and the three levels of treatments became 0.52l/s, 0.79l/s, and 1.05l/s.

Table2.2 Experimental treatment

Flow Rate	Furrow Length		
	L_1(16m)	L_2(32m)	L_3(48m)
Q_1(0.52l/s)	L_1Q_1 (*T1*)	L_2Q_1 (*T4*)	L_3Q_1(*T7*)
Q_2(0.79l/s)	L_1Q_2 (*T2*)	L_2Q_2 (*T5*)	L_3Q_2 (*T8*)
Q_3(1.05l/s)	L_1Q_3 (*T3*)	L_2Q_3 (*T6*)	L_3Q_3 (*T9*)

The experimental field was arranged in a split plot design with three replications where furrow length used as a main plot factor and flow rate as sub plot factor.

The main plot factor initially assigned randomly in to three sub-blocks. The three flow rate levels randomly assigned within each sub-blocks. The block and plot spacing was 2.0m and 0.75m respectively. The furrow spacing was equal to row spacing of the maize crop. The experimental field had a total number of 81 furrows and 0.24 ha of land size.

2.3 Climatic Data Collection

Long-term (1977 to 2010 or 34years) monthly climatic data for the area was collected from Melkassa Agricultural Research Center, meteorological observatory station as indicated in Table2.3.

Table2.3 Long-term monthly average climatic data and ETo of the experimental area

Month	Tmean, °c		RH, %	U2, m/s	SH, hr	RF, mm	ETo, mm/day
	T_{max}	T_{min}					
January	28.49	12.11	51.9	3.17	9.17	14.3	5.67
February	29.76	13.84	49.9	3.27	9.17	28.1	6.50
March	31.09	15.54	50.4	3.12	8.67	52.7	6.72
April	31.12	15.92	52.6	2.83	8.51	52.3	6.47
May	31.82	16.0	51.8	2.72	9.11	55.8	6.48
June	30.8	16.84	54.8	3.31	8.7	73.7	6.34
July	27.59	16.17	66.6	3.28	7.22	191	5.09
August	26.94	15.83	70.9	2.54	7.27	200	4.63
September	28.42	14.87	66.7	1.79	7.7	91.2	4.73
October	29.53	12.08	50.9	2.39	8.82	35.8	5.67
November	29.18	11.05	46.9	2.99	9.98	19.2	6.03
December	28.36	10.92	50.6	3.17	9.73	11.6	5.59
Average	29.43	14.26	55.4	2.88	8.67	68.8	5.83

RH – Relative humidity U2 – Wind velocity
SH – Sunshine RF – Rainfall

2.4 Crop and Irrigation Water Requirement

The climatic data were used to estimate the reference crop evapotranspiration by using CROPWAT 8 model. The Crop water requirement was determined by the sum of depth of water required (d_{net}) to the crop throughout the growing season. In this case, the net irrigation requirement was calculated using water balance equation.

$NIR = d_{net} - Pe - GW - \Delta SW$……………………..(2)

Where

NIR = Net irrigation requirement, mm

d_{net} = Net depth of water required, mm

Pe = Effective precipitation, mm

GW = Ground water recharge, mm

ΔSW = Change in soil water content, mm

Inflow time (T)

In order to irrigate each furrow, the time of application was determined by using [7].

$T= \frac{Fg \times W \times L}{60 \times Qo}$……………………………..…..……(3)

Where

T = Inflow time of cutoff, min

L = Furrow length, m

W = Furrow spacing, m

F_g = Gross depth of application, mm
Q_o= Flow rate, l/s

Discharge through Siphon

The flow rate was diverted to individual furrow through 4.2 centimetre diameter siphon. The head required to divert each flow rate from canal was determined using the following formula [11].

$$Q = C_d \times A \times \sqrt{(2gH)} \times 10^{-3} \qquad (4)$$

Where

Q = Flow rates in siphon, l/s
A = Cross sectional area of siphon, cm^2
g = Gravitational acceleration, 981 cm/s^2
H = Effective head, cm
C_d= discharge coefficient,0.584

2.5 Irrigation Performance Indicators Application efficiency

It is the ratio between the quantities of irrigation water effectively used by the crop to the quantity of water supplied to the field[8].

$$E_a = \frac{V_s}{V_{ap}} \times 100 \qquad (5)$$

Where

E_a = Application Efficiency, %
V_s= Stored water volume in root zone, m^3
V_{ap}= Volume of water applied, m^3

Storage efficiency

It measures adequacy of irrigation water (Hart *et al.*, 1979).

$$E_s = \frac{W_s}{W_n} \times 100 \qquad (6)$$

Where

E_s = Storage efficiency, %
W_s = Stored water depth in root zone, cm
W_n = Required depth of water, cm

Surface runoff ratio

The surface runoff from the furrow was measured by making dug out at the out let of test furrow [9].

$$SRR = \frac{V_{sr}}{V_{ap}} \times 100 \qquad (7)$$

Where

SRR = Surface runoff ratio, %
V_{sr} = Surface runoff volume, m^3
V_{ap} = volume of water applied, m^3

Deep percolation ratio

It is the ratio of depth of water infiltrated below the crop root zone and applied and. [19] defined DPR mathematically in the following formula.

$$DPR = \frac{D_p}{D_n} \times 100 \qquad (8)$$

Where

DPR = deep percolation ratio, %
D_p = depth of water percolated below root zone, cm
D_n = depth of water needed in the root zone, cm

Distribution uniformity (DU)

It is the measure of how uniformly irrigation water infiltrated to the root depth along the furrow length [19].

$$DU = \frac{Zmin}{Zave} \times 100 \qquad (9)$$

Where

DU = Distribution uniformity, %
Z_{min} = Minimum infiltration depth, cm
Z_{ave} = Average depth of infiltration, cm

2.6 Yield and Crop Water Use Efficiency (CWUE)

CWUE is the quantity of crop yield (Kg/ha) produced per unit depth (mm) of water used [17].

$$CWUE = \frac{Y}{ETc} \qquad (10)$$

Where

CWUE = Crop water use efficiency, kg/ha-mm
Y = Yield of crop, kg/ha
ETc = Crop evapotranspiration, mm

2.7 Data analysis

The results of yield, water use efficiency and irrigation performance indices were subjected to Analysis of Variance using SAS 9.2 program. For comparing means of the least significant difference (LSD) test at 5% and 1% probability level was applied.

III RESULTS AND DISCUSSION

Crop and irrigation water requirement

The crop was planted at 16-May, 2015. The need of irrigation in the area is critical. The difference between the crop (681.4mm) and irrigation (628.11mm) water requirement was 53.3mm throughout the crop growing season.

Table 3.1 Crop and irrigation water requirement

Irrigation Event	d_{net}, mm	P_e, mm	NIR, mm	GIR, mm
16/05/2015	16.12	0.0	16.12	23.03
22/05/2015	16.12	0.0	16.12	23.03
28/05/2015	16.12	0.0	16.12	23.03
04/06/2015	18.12	0.0	18.12	25.89
11/06/2015	21.38	0.0	21.38	30.54
19/06/2015	43.27	0.0	43.27	61.81
30/06/2015	69.41	0.0	69.41	99.16
11/07/2015	93.36	24.8	68.56	97.94
23/07/2015	93.36	0.0	93.36	133.37
05/07/2015	98.86	15.0	83.84	119.77
18/08/2015	98.86	5.8	93.06	132.94
31/08/2015	96.45	7.7	88.75	126.79
Total	681.4	53.3	628.11	897.30

Pe – effective precipitation NIR – Net irrigation requirement GIR – Gross irrigation requirement

3.1 Maize Grain Yield

The effect of flow rate on maize yield was significant ($p<0.01$). The average grain yield gained was 5.75ton/ha. The maximum and minimum yield was obtained from the combined treatment of L_3Q_2 (6.85 t/ha) and L_1Q_1 (4.85 t/ha) respectively. When the maximum yield obtained, greater performance in application efficiency and adequacy of water was recorded. However, treatment L_1Q_1 showed lower application efficiency and adequacy of water in the crop root zone that might led to provide the least yield. The mean grain yield has increased from 4.98 to 5.6ton/ha when the flow rate changed from 0.52l/s to 0.79l/s and the

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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improved application, storage efficiency. However, the rise of flow rate from 0.79l/s to 1.05l/s could not increases the yield because most of the water has turned in to surface runoff. The effect of furrow length and its interaction with flow rate could not show significant effect ($P \leq 0.05$) on the grain maize yield. The maximum and minimum mean grain yield gained was 5.81 ton/ha (32m) and 5.66 ton/ha obtained from 48m of furrow length. Although the yield has improved when the furrow length was increased from 16m (5.78ton/ha) to 32m (5.81ton/ha), the yield has turned to decline in to 5.66 ton/ha (48m). As a result, furrow length could not show significant effect on the grain yield.

3.2 Maize Water Use Efficiency

The mean water use efficiency (WUE) was 8.44 Kg/ha-mm. The effect of flow rate on the WUE was significant ($p<0.01$). The mean WUE has increased when the flow rate changed from 0.5l/s to 0.79l/s, however, when the flow rate was increased from 0.79 to 1.05l/s, WUE has reduced but higher than 0.5l/s. The highest WUE was 10.06 Kg/ha-mm was attained by L_3Q_2 due to the presence of more moisture in the root zone as compared to the other treatments. The effect of furrow length was not significant on the WUE. The trend of mean WUE resulted with the change of furrow length and flow rate is similar to that of grain yield.

Table 3.2 Treatment grouping on the effect of furrow length and flow rate

Treatment	GY	CWUE	TDM	PH	GW	Ea	DPR	SRR	Es	DU
	Ton/ha	Kg/ha-mm	Ton/ha	cm	gm	%	%	%	%	%
L_1Q_1 (T1)	4.85^{c}	7.12^{c}	13.97^{ab}	133.4^{c}	29.20^{b}	26.73^{e}	11.79^{b}	61.47^{c}	38.18^{e}	66.47^{b}
L_1Q_2 (T2)	6.78^{ab}	9.95^{ab}	15.29^{ab}	145.5^{abc}	29.30^{b}	25.20^{f}	9.58^{c}	65.17^{b}	36.04^{f}	73.7^{a}
L_1Q_3 (T3)	5.7^{bc}	8.37^{bc}	15.13^{ab}	164.1^{ab}	30.00^{b}	21.85^{g}	8.15^{c}	70.0^{a}	31.65^{g}	78.3^{a}
L_2Q_1 (T4)	4.97^{c}	7.29^{c}	13.05^{c}	147.5^{abc}	28.10^{b}	30.69^{d}	16.07^{a}	53.23^{de}	44.4^{d}	31.57^{e}
L_2Q_2 (T5)	6.78^{ab}	9.94^{ab}	16.43^{a}	151.7^{abc}	30.10^{b}	36.14^{b}	12.78^{b}	51.1^{e}	52.36^{b}	41.77^{d}
L_2Q_3 (T6)	5.7^{bc}	8.36^{bc}	15.61^{ab}	156.87^{ab}	31.38^{b}	32.80^{c}	12.72^{b}	54.47^{d}	47.00^{c}	59.5^{c}
L_3Q_1 (T7)	5.11^{c}	7.5^{c}	13.35^{c}	143.53^{bc}	27.82^{b}	30.64^{d}	17.16^{a}	52.2^{e}	43.76^{d}	29.67^{e}
L_3Q_2 (T8)	6.85^{a}	10.06^{a}	15.87^{ab}	153.3^{abc}	39.55^{a}	38.52^{a}	8.46^{c}	53.0^{de}	56.0^{a}	43.67^{d}
L_3Q_3 (T9)	5.01^{c}	7.35^{c}	14.78^{ab}	164.5^{a}	30.81^{b}	32.74^{c}	12.22^{b}	55.07^{d}	46.76^{c}	57.77^{c}
Mean	5.75	8.44	14.83	151.1	30.7	30.6	12.1	57.3	44.0	53.6
LSD 5%	1.09	1.6	3.02	20.97	5.02	1.38	2.19	2.19	1.74	6.92
CV (%)	10.9	10.9	11.8	8.01	9.4	2.6	10.5	2.22	2.28	7.45

Note: a, b, c groups

GY = Grain yield; CWUE = Crop water use efficiency; TDM = Total dry matter (including grain yield); PH = Plant height in centimeter; GW= Maize grain weight.

3.3 Irrigation Performance Indicators

Application Efficiency (Ea)

Ea was significantly affected ($p<0.01$) by furrow length and interaction effect. The average application efficiency was increased from 24.6 to 34.0% when the furrow length increased from 16m to 48m. The maximum application efficiency attained by [2] was 82% through the use of flow rate of 0.3m^3/min over 410m furrow length. It is an evident that by using higher flow rate combined with long furrow length, Ea can be enhanced. Ea was significantly affected ($p<0.01$) by flow rate increment. In other hand, Ea was increased from 29.3 to 33.3% while the flow rate was changed from 0.52 to 0.79l/s, however, it has reduced as the flow rate increased from 0.79 to 1.05l/s.The highest value of Ea was 38.52% found from the treatment L_3Q_2 and the minimum Ea was 21.85% resulted from L_1Q_3.

Deep percolation ratio (DPR)

The effect of furrow length and interaction effect was significant ($P<0.01$) on the mean DPR. DRP has increased when the furrow length was increased from 16m to 32m. Longer furrows facilitate the water to stay in extended contact time with the soil storage but short furrow reduces the water contact time. In [10] study, the mean DPR was 25.5 to 30.37% obtained from 25m to 50m furrow length. In his study, the DPR results were higher than this study due to the use of flatter slope and slower flow rate. The flow rate was significantly ($P<0.01$) affected the DPR. The minimum and maximum percolation ratio gained as 8.15% from L_1Q_3 and 17.16% on L_3Q_1 respectively. The slower advance rate of lower flow rate at longer furrow length could provide the higher deep percolation loss.

Surface runoff ratio (SRR)

The difference between the mean SRR was significant ($P<0.01$) due to variation in furrow length and interaction. The highest percent of the applied water lost as runoff was gained from 16-metre furrow length that was 65.5% which was significant over the result obtained from 32m and 48m of furrow length. In [16] work, the range of SRR was 47.8 to 22.0% for furrow length of 10m to 40m. Very short furrow whose tail end remained opened are followed by too much surface runoff [4].

The effect of flow rate was significant ($P<0.01$) on SRR. The results of mean SRR were in increased trend with flow rate that was in agreement with [16] and [10]. This might be resulted because of fastest flow rate has reduced the infiltration contact time and increased the tail water loss. The results of SRR gained from [16] showed that when the flow rate increased from 0.4l/s to 0.8l/s, SRR has increased from 24.9 to 44.6%. In this study, the flow rates were higher and resulted greater fraction of surface runoff.

Storage efficiency (Es)

The storage efficiency is used to measure adequacy of water actually stored in the root zone [4]. There was a significant effect ($P< 0.01$) on Es due to furrow length and its interaction with flow rate. The rise of furrow length from 16 to 48 has improved the storage efficiency by 27.7%. The maximum and minimum storage efficiency achieved were 56.0% and 31.65% that was measured from L_3Q_2 and L_1Q_3 respectively. Longest furrow has shown more infiltrated water due to more contact time. Short furrows provided lower performance of storage efficiency.
The flow rate has a significant ($P<0.01$) effect on Es. The mean Es obtained in this study are very low as compared to 80% of Es gained for optimal bean yield [15]. In this experiment, the Es was highly reduced by use of short furrow where most of the water lost through runoff.

Distribution Uniformity (DU)

DU was significantly ($p<0.01$) influenced by furrow length and the interaction effect. The mean DU was reduced when the furrow length increased from 16m to 48m. Usually the variation of slope, furrow dimensions and contact time in the use of short furrows are very low as compared to longer furrows. As a result, more uniformity occurred in short furrows and the relationship between DU and furrow length was reverse.
The DU was significantly ($p<0.01$) influenced by the flow rate. Unlike to furrow length, the rise in flow rate from 0.52 to1.05l/s improved the DU. The increasing trend of DU with flow rate was in agreement with [16] and [10]. L_1Q_3 has resulted highest mean DU (78.35%) due to the fast advancing rate and low contact time variation of short furrow length. Whereas, 0.52l/s combined with the longest furrow length (L_3Q_1) could result the lowest DU, 29.67%. In [10] study, the Mean DU was lower (25.3 to 44.8%) due to the use of lower flow rate (0.3 l/s to 0.5 l/s).

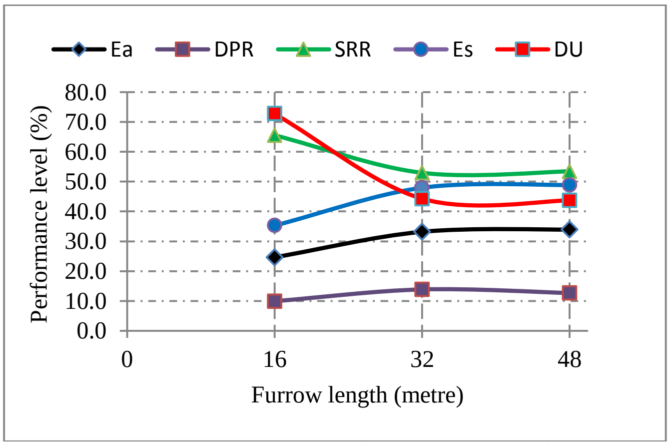

Figure3.1 Relationships between furrow length and performance indicators

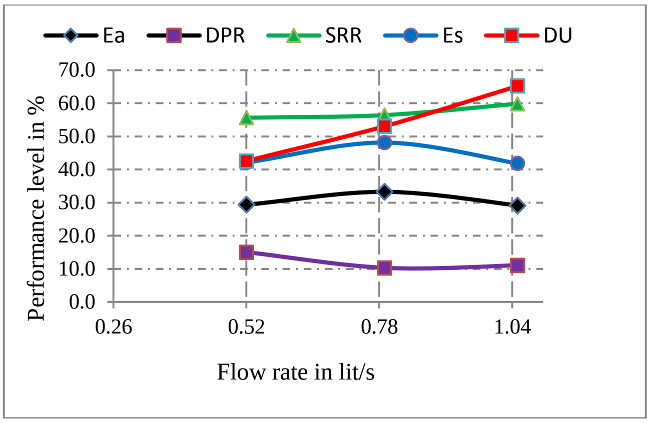

Figure3.2 Relationships between flow rates and performance levels

IV CONCLUSION

This study showed that the use of different furrow length and flow rate has shown different outcomes. Flow rate has a significant effect of on the yield, crop water use efficiency, and irrigation performance indicators. The rise of flow rate from 0.52l/s to 0.79l/s has improved certainly the yield, Ea, Es, DPR, and DU; however, SRR was aggravated. The use of 1.05l/s was seen with highest SRR, lowest adequacy of water and low yield production. In the situation of furrow length rise from 16m to 48m the yield, Ea and Es was improved; DU was minimized; and DPR and SRR were increased. In this study, the use of short furrow length was the major contributor of water loss through surface runoff and reduced yield. Hence, in the utilization of fragmented farm size, the combination of 48m furrow length and 0.79l/s flow rate can be used for better crop yield, and irrigation efficiency. In addition, the users should give much emphasis in reducing furrow gradient in order to improve the distribution uniformity. 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.

ACKNOWLEDGEMENT

The authors highly acknowledged the Ethiopian Institute of Agricultural Research for financial support. The authors also express appreciation for Teppi National Spice Research Center and Melkassa Agricultural Research Center Staff members for their holistic support throughout the experimental work.

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