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# Effect of Appropriate Furrow Length and Flow Rate for Potato (*Solanum tuberosum L*) Production Using Furrow Irrigation Under Smallholder Farmers Condition at Kersa, South Western Ethiopia

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**Abstract:** Furrow length and water flow rate had a significant effect on crop yield, crop water use efficiency and irrigation performance indicators. Therefore, objective the study was to determine optimum combination of furrow length and flow rate to enhance irrigation efficiency. Field experiment was carried out at Kersa woreda, Jimma Zone, South Western part of Ethiopia, during cropping season of 2019, 2020 and 2021 for three consecutive years using Belete potato variety as a test crop. The treatment comprised three furrow length (50, 30 10 m) and three flow rates (0.45, 0.67, and 0.89l/s) laid out in split plot design with three replications where furrow length used as the main plot and flow rate as sub-plot. Results of over year analysis showed that tuber yield, biomass yield and tuber diameter significantly affected by different furrow length and flow rates. The highest and lowest tuber yield was obtained from L2Q1 (39.49 t/ha) and L3Q2 (29.09t/ha) respectively. The highest Biomass yield of 35.75 ton/ha was obtained from L2Q1 treatments whereas the lowest (20.34t/ha) recorded from L1Q3 treatment. Interaction of furrow length and flow rate does not affect water productivity, water application efficiency and deep percolation ratio. Similarly furrow length was not significant ($p>0.05$) on water productivity of potato. However flow rate influences water productivity significantly ($p<0.05$). The water productivity for both furrow length and flow rate ranges from 0.41 to 0.45 $Kg/m^3$. Both furrow length and flow rate had significant ($p<0.05$) impact on irrigation water application efficiency. The maximum water application efficiency was obtained from 30m furrow length (29%) and 0.67l/s flow rate (27%). Based on the current finding potato belete variety resulted in maximum yield at combination of 30m furrow length and 0.89l/s flow rate (L2Q1) using furrow irrigation.

**Keywords:** Potato, Furrow Length, Water Productivity, Tuber Yield

## 1. Introduction

The agriculture system in Ethiopia is dominated by smallholders with highly fragmented pieces of lands. Proper management of irrigated agriculture is dependent on adequate water supply of useable quality at correct quantity. In addition the Ethiopia irrigated agriculture is plagued by inappropriate on farm water management, which resulted in adverse effects such as no uniform water distribution, unbalanced crop growth, water logging, salinity, and erosion, thereby led to low production and productivity. Consequently, most of the developed irrigation schemes are benefiting under their designed potential area and period [13, 2] Water scarcity is a major constraint for food production, particularly in arid and semi-arid environments. In this regard, selecting the best irrigation technique is crucial to overcome water scarcity and enhance water productivity (WP) with no significant yield loss [11].

Minda Tadesse et al. [10] showed that Potato is one of the most popular and the most cultivated vegetables in Ethiopia in general and in Jimma Zone in particular as it is considerably important cash crop. Farmers in the study area produce Potato as a cash vegetable using furrow irrigation methods. However Design and operation of furrow irrigation should be based on optimum combination of the length, the flow rate, to get better yield by improving water productivity. Regarding design of flow rates and furrow length for small scale and smallholder farmer practicing irrigation little information is available. According to the research [5] small holder farmers are being practiced the size of furrow lengths in the range of 10 to 30m used for production of small vegetables and cereals. The flow rates used are also dependent on the incoming flow rates in to the field.

Proper design of furrow length and flow rate Improve of water productivity in furrow irrigation. Moreover Yigezu, T. T. et al. [14] concluded that furrow length and flow rate has a significant influence of on the crop yield, crop water use efficiency and irrigation performance indicators. Accordingly, use of very low flow rate result deep percolation while high flow rate leads to surface runoff and leaching of soil nutrient. In addition, it leads to frequent need of furrow construction, increased erosion potential, salinity hazards, higher yield loss and lower economical profit [12]. As a result of this, it is important to determine the combination of flow rate and furrow length to maximize the irrigation performance and crop productivity while conserving the soil and water resource. This study was conducted based on the objective to avail information on appropriate furrow length and flow rate combination under smallholders' conditions for production potato under furrow-end closed irrigation practice.

# 2. Materials and Methods

### 2.1. Description of the Study Area

The field experiment was conducted at Jimma zone, Kersa woreda (Girma kebele), South Western Ethiopia. The area situated at 7.74808°N latitude, 37.097976°E longitude and average altitude of 1800 m (masl). An area receives an average annual rainfall of 1728.67mm, with the mean maximum and minimum monthly values of 278.86mm and 31.17mm, occurring during July and January respectively. The average maximum temperature varies from 26°C to 31°C while the mean minimum temperature varies from 10.8°C to 13°C. Sandy clay Loam and Clay loam soil textures were the dominant soils of the area. In general, the area is characterized by tropical and warm to cold humid temperate climates.

### 2.2. Procedures of the Experiment

The study site was first characterized based on field irrigation practice like furrow slope, furrow length and flow rate to have detail information of current farmer practice on furrow irrigation. The experiment was undertaken during the dry seasons of 2019, 2020 and 2021. Composite disturbed soil samples was collected from the experimental site at interval of 30 cm up to the effective potato root zone depth for the determination of different physical soil parameters like soil texture, field capacity and permanent wilting point. Similarly, undisturbed soil samples were collected from similar depth intervals for the determination of bulk density of the soil. Common land preparation activities like land ploughing, leveling and removal of crop residue was carried out at the beginning of the experiment. The full doze of DAP (150 kg/ha) was applied at planting time, whereas as Urea (180 kg/ha) was applied in two splits 90 kg during planting and the rest 90 kg at 25 days after planting.

### 2.3. Design of the Experimental

The experiment has two factors; furrow length and irrigation water flow rate laid out in split plot design. Three levels of furrow length used as main plots and three levels of flow rate were arranged in sub plots with three replications. Treatments were assigned randomly to each plot and block was taken as replications. Based on the slope of the farm (furrow slope) and soil type of the farm maximum non erosive flow rate was determined using the following formula [6]. After the estimation of maximum non-erosive flow rate, three levels of flow rates 50%, 75%, and 100% of the maximum non-erosive flow rate was used as treatments.

$$Q = \alpha S^{-\beta} \quad (1)$$

Where: Q: maximum non erosive flow rate (lit/sec)

$\alpha$ and $\beta$: coefficient which depend on soil texture (soil type)

S: furrow slope (%)

The experimental field had an average furrow bed slope of 0.6% and medium textured soil. The maximum non-erosive flow rate was estimated as 0.89l/s and the three levels of treatments became 0.45l/s, 0.67l/s and 0.89l/s.

***Table 1.*** *The coefficient of discharge parameters.*

| No | Soil group | α | β |
|---|---|---|---|
| 1 | Heavy texture | 0.892 | 0.937 |
| 2 | Medium-heavy texture | 0.988 | 0.55 |
| 3 | Medium texture | 0.613 | 0.733 |
| 4 | Light texture | 1.111 | 0.615 |
| 5 | Very light texture | 0.665 | 0.548 |

The total experimental area has three replications. Each replication (blocks) was then subdivided into three main plots, and each of the three main plots was subdivided into three sub-plots. Therefore, the entire experimental site was sub divided into twenty seven experimental units (sub-plots). Each main plot was contain three of the furrow length treatments and each sub plots has three furrows. The middle furrow was used for test furrow and the furrow on both boarder sides was used as buffer for the destructive sampling. Total number of furrows was 81. The main plot factor (furrow length) was initially assigned randomly. The three flow rate levels was randomly assigned within each main plot. The block and plot spacing was 3 m and 2m, respectively.

Treatments:-Furrow length includes 10m, 30 m and 50m and Flow rate includes 100%Q, 75%Q and 50%Q.

***Table 2.*** *Treatment setting.*

| Flow rate (l/s) | Furrow length (m) | | |
|---|---|---|---|
| | L1 (10m) | L2 (30m) | L3 (50m) |
| Q1 (0.45) | L1Q1 | L2Q1 | L3Q1 |
| Q2 (0.67) | L1Q2 | L2Q2 | L3Q2 |
| Q3 (0.89) | L1Q3 | L2Q3 | L3Q3 |

Long-term meteorological parameters like maximum and minimum air temperature, relative humidity, wind speed and sunshine hours was collected for the determination of reference evapotranspiration ($ET_{o)}$ of the study area using CropWat 8.0 software.

***Table 3.*** *Long term Climatic Data of the study area (1985-2020).*

| Month | Rf (mm) | Tmin (°C) | Tmax (°C) | RH (%) | S. sh (hrs) | WS | ETo |
|---|---|---|---|---|---|---|---|
| Jan | 31.2 | 11.1 | 27.2 | 61.9 | 7.97 | 1.07 | 3.86 |
| Feb | 31.52 | 11.17 | 27.25 | 56.56 | 8.03 | 1.19 | 4.33 |
| Apr | 94.28 | 12.54 | 28.21 | 57.36 | 7.5 | 1.27 | 4.5 |
| Mar | 132.5 | 12.85 | 27.34 | 63.6 | 7.23 | 1.3 | 4.34 |
| May | 202 | 12.8 | 26.32 | 73.71 | 6.89 | 1.26 | 4.16 |
| Jun | 255.3 | 12.45 | 24.66 | 78.87 | 5.69 | 1.15 | 3.67 |
| Jul | 279.96 | 12.34 | 23.03 | 83.47 | 3.56 | 1.09 | 3.07 |
| Aug | 278.9 | 12.23 | 23.21 | 84.09 | 3.61 | 1.07 | 3.21 |
| Sep | 219.1 | 12.04 | 24.28 | 81.5 | 5.06 | 1.05 | 3.67 |
| Oct | 116.57 | 11.47 | 25.44 | 71.9 | 7.69 | 1.01 | 3.94 |
| Nov | 48.29 | 10.86 | 26.2 | 66.32 | 8.16 | 0.96 | 3.84 |
| Dec | 33.19 | 10.65 | 26.52 | 62.21 | 7.96 | 0.97 | 3.7 |

*Tmin is minimum temperature, Tmax is maximum temperature, RH is relative humidity, WS is wind speed, S. sh is sunshine hour, Rf is monthly rainfall and ETo is reference evapotranspiration*

### 2.4. Irrigation Water Requirement

The irrigation water requirement was determined by the sum of depth of water required (dnet) to the crop throughout the growing season.

$$In=CWR-R \tag{2}$$

where, In=net irrigation water requirement (mm), CWR=crop water requirement (mm) and

Re= effective rainfall (mm)

The gross irrigation water requirement was calculated using:

$$Ig = \frac{In}{Ea} \tag{3}$$

Where Ig is growth irrigation and Ea is application efficiency for furrow irrigation.

To apply the maximum depth of application to the test (optimal) furrow and its buffer furrows with the selected optimal flow rate, the time of cutoff was known [7].

$$T= \frac{Ig \times W \times L}{60 \times Qo} \tag{4}$$

Where

T = Inflow time of cutoff (min),

L = Furrow length (m),

W = Furrow spacing (m),

$I_g$= Gross depth of application (mm),

$Q_o$= Flow rate (l/s).

The selected flow rate can be delivered to the test and buffer furrow through Parshall-flume. The diversion of selected flow rate in to furrow was done using Parshall flume.

$$Q = K \times H^{1.55} \times 1000 \tag{5}$$

Where Q = flow rate in the Parshall flume (l/s), K = Coefficient of discharge, fraction

H = Depth of flow in the Parshall flume (cm)

### 2.5. Indicators of Irrigation Performance

#### 2.5.1. Water 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 [9]:

$$Ea= \frac{Ws}{Wf} *100 \tag{6}$$

Where: - Ea: application efficiency (%); Ws: average depth water stored in the root zone of the plant (mm); Wf: average water delivered to the irrigation field in depth (mm).

#### 2.5.2. Deep Percolation Ratio

It is the ratio of depth of water infiltrated below the crop root zone and applied and calculated by using the following equation [3].

$$DPR = 100 - Ea - R \tag{7}$$

Where: -DPR: Deep percolation ratio (%); Ea: application efficiency (%); RR: runoff ratio (%)

Data on tuber yield, above ground biomass yield and tuber diameter data was recorded for three consecutive years. Data on water productivity was calculated based on ratio of economic yield obtained to seasonal net irrigation amount using the following formula [9].

$$\text{Water productivity} \left(\frac{kg}{m^3}\right) = \frac{\text{yield (kg)}}{\text{Seasonal net irrigation depth amount } (m^3)} \tag{8}$$

### *2.6. Physical Soil and Chemical Characteristics*

Soil sample for determination of moisture content at field capacity (FC), permanent wilting point (PWP) soil texture and bulk density was collected from three depth 0-30cm, 30-60cmand 60-90cm at three locations along the diagonal of the experimental field. Soil pH was determined for the identification of whether the soil has acidity or salinity problem. It will measure in 1: 2.5/soil: water mixture by using PH meter. Total Nitrogen was determined by Kjeldhal method in the laboratory. Titration method, which is oxidation under standardized condition with potassium dichromate in sulpheric acid, was used for organic carbon determination.

### *2.7. Statistical Analysis*

Collected data were subjected to ANOVA using R software (version 4.0.0). For the variance analysis, mean comparisons were executed using least significant difference (LSD) at 5% probability level when treatments show significant difference to compare difference among treatments mean.

## 3. Result and Discussion

### *3.1. Soil Physical Properties*

Soil bulk density of the experimental area ranges from 1.28-1.41g/cm$^3$. The results from study showed that bulk density increases with soil depth. Regarding particle size analysis average composition of Clay, Silt, Sand and percentages were 24.7%, 12.3% and 63%, respectively. Thus, according to the USDA soil textural classification, the soil texture of the experimental site was classified as sandy clay loam soil (Table 4). Average moisture content on mass base at field capacity and permanent wilting point were 39.79% and 29.56 %, respectively.

***Table 4.*** *Soil physical properties and texture of the study site.*

| Soil depth (cm) | FC (%) | PWP (%) | Bd (g/cm$^3$) | Clay | silt | sand | class |
|---|---|---|---|---|---|---|---|
| 0-30 | 39.58 | 29.4 | 1.28 | 26 | 19 | 55 | SCL |
| 30-60 | 38.5 | 31.8 | 1.37 | 28 | 6 | 66 | SCL |
| 60-90 | 41.3 | 27.5 | 1.41 | 20 | 12 | 68 | SCL |
| average | 39.79 | 29.56 | 1.35 | 24.7 | 12.3 | 63 | SCL |

*SCL=Sandy clay loam, Bd=soil bulk density, FC=soil field capacity and PWP=Soil permanent wilting point.*

The result of soil chemical analysis showed that, the average pH value of the soil ranges from 5.76 to 5.96. The average soil PH of the study site was 5.85 (Table 5). The average electrical conductivity of the soil was 0.17 ds/m. According to USDA soil classification, a soil with electrical conductivity of less than 2.0 dS/m at 25°C and pH less than 8.5 are classified as normal soil. The average total organic carbon content of the testing soil is 1.6% (table 5) which is rated as moderate and gives average structural condition and stability to the soil [1].

***Table 5.*** *Soil chemical properties of experimental site.*

| soil depth | PH (1: 2.5) | EC (dS/m) | TN (%) | TOC (%) |
|---|---|---|---|---|
| 0-15cm | 5.76 | 0.12 | 0.24 | 1.81 |
| 15-30cm | 5.82 | 0.14 | 0.19 | 1.55 |
| 30-60cm | 5.96 | 0.09 | 0.15 | 1.43 |
| Average | 5.85 | 0.17 | 0.19 | 1.60 |

*PH=pH of soil, EC=electrical conductivity of soil, OM= organic matter, TOC= Total organic carbon, TN= total nitrogen.*

### *3.2. Influence of Furrow Length and Flow Rate on Tuber Yield of Potato*

From the experiment, interaction of furrow length and flow rate showed highly significant ($p<0.01$) influence on tuber yield of potato. The minimum and maximum tuber yield of 29.09 and 39.49 t/ha were recorded from combination of L2Q1 and L3Q2, respectively. The rise of flow rate from 0.45 l/s to 0.89 l/s could decrease the tuber yield since most of the water has turned in to surface runoff. Similarly, the tuber yield could not increase as furrow length increased from 30m to 50m because larger furrow length could result in high deep percolation (Table 6). Potato tuber yield increased as the inflow rate increased due to the enhanced irrigation uniformity achieved by higher inflow rate up to 30m furrow length. Beyond 30m large amount of water might penetrates into soil layers and will be lost through deep infiltration which is in line with previous studies [14].

### *3.3. Biomass Yield and Tuber Diameter*

From over year analysis, interaction of furrow length and flow rate had significant influence ($p<0.05$) on potato tuber diameter and biomass yield. Maximum tuber diameter of 12.7cm was obtained under L2Q1 treatment (30m and 0.45l/s) followed by L2Q2 (30m and 0.67l/s) (Table 6). The maximum biomass was recorded from combination of 30m and 0.45l/s (35.75 ton/ha). the minimum biomass yield and tuber diameter was recorded from L3Q3 treatment which is 23.4 ton/ha and 6.8cm respectively (table). The decreased biomass yield and tuber diameter with furrow length increment might be due to high deep percolation during treatment application. In agreement with this study [11] described that reduction of tuber diameter and biomass yield with flow rate increment was due to faster water movement, leading to less infiltration and high surface runoff.

***Table 6.*** *Interaction effect of furrow length and flow rate on tuber yield, biomass yield and tuber diameter of potato.*

| Treatment | Tuber Yield (ton/ha) | Biomass yield (ton) | Tuber diameter (cm) |
|---|---|---|---|
| L1Q1 (T1) | 31.81[e] | 23.54[f] | 8.2[de] |
| L1Q2 (T2) | 36.73[c] | 27.45[e] | 8.2[de] |
| L1Q3 (T3) | 30.09[g] | 20.34[g] | 7.9[de] |
| L2Q1 (T4) | 39.49[a] | 35.75[a] | 12.7a |
| L2Q2 (T5) | 37.12[b] | 32.3[b] | 10.6[b] |
| L2Q3 (T6) | 35.34[d] | 29.77[c] | 9.6[c] |
| L3Q1 (T7) | 31.63[f] | 28.77[d] | 8.8[cd] |
| L3Q2 (T8) | 29.09[i] | 24.2[f] | 7.8[ef] |
| L3Q3 (T9) | 29.69[h] | 23.4[f] | 6.8[f] |
| Mean | 33.45 | 27.28 | 8.9 |
| LSD 5% | ** | * | * |
| CV (%) | 9.1 | 11.6 | 16.5 |

***=highly significant at (p<0.01) level of probability and *=significant at (p<0.05) level of probability, Means followed by different letters in a column differ significantly and those followed by the same letter are not significantly different.*

### *3.4. Effect of Furrow Length and Flow Rate on Water Productivity*

From analysis of variance there is no significance difference (P > 0.05) among furrow length and interaction of furrow length and flow rate on water productivity. However, flow rate influences water productivity significantly (p<0.05). The maximum water productivity was obtained from Q3 (0.45 kg/$m^3$) followed by Q1 (0.44kg/$m^3$) inflow rate which is statistically similar (Table 7). In line with this [4] flow rate was the main irrigation decision variables currently affecting yield and water productivity of onion at farm level.

### *3.5. Effect of Furrow Length and Flow Rate on Ea and DPR*

From analysis of variance, water application efficiency was not affected by interaction effect of furrow length and flow rate. However both furrow length and flow rate affects Ea significantly (p<0.05). The study showed that the highest Ea of 29% and 27% obtained from L2 and Q1, respectively. *Ea* increased as the furrow length and flow rate increased up to furrow length reached 30m and 0.67l/s respectively. From three years data average values of Ea were 24%, 27%, and 26% for Q1, Q2, and Q3, respectively (Table 7). Regarding deep percolation ratio, their interaction as well as furrow length and the flow rate were not significant. However, L3 and Q1 treatment produced the highest DPR values of 77% and 76% respectively.

***Table 7.*** *Effect of furrow length and flow rate on water WP, Ea and DPR.*

| Furrow length (m) | WP | Ea | DPR |
|---|---|---|---|
| L1 (10) | 0.45[a] | 0.25[b] | 0.75 |
| L2 (30) | 0.41[b] | 0.29[a] | 0.76 |
| L3 (50) | 0.45[ba] | 0.23[b] | 0.77 |
| LSD (5%) | Ns | * | ns |
| CV (%) | 10.8 | 8.3 | 4 |
| Flow Rate (L/sec) | | | |
| Q1 (0.45) | 0.44[ba] | 0.24[b] | 0.76 |
| Q2 (0.67) | 0.41[b] | 0.27[a] | 0.75 |
| Q3 (0.89) | 0.45[a] | 0.26[ba] | 0.75 |
| LSD (5%) | * | * | ns |
| CV (%) | 7.5 | 7.1 | 1.6 |

*Ea=Water application efficiency, WP=water productivity and DPR=Deep percolation ratio**=highly significant at (p<0.01) level of probability and *=significant at (p<0.05) level of probability, Means followed by different letters in a column differ significantly and those followed by the same letter are not significantly different.*

## 4. Conclusion

The finding showed that interaction of flow rate and furrow length had shown significant outcomes. Tuber yield, biomass yield and tuber diameter of potato had significantly affected by Flow rate. The maximum tuber yield and tuber diameter of 29.09 ton/ha and 12.7cm were recorded from combination of L2Q1, respectively. The rise of flow rate from 0.67l/s to 0.89l/s could decrease the tuber yield since most of the water has turned in to surface runoff. Similarly the tuber yield could not increase as furrow length increased from 30m to 50m because larger furrow length could result in high deep percolation. Both furrow length and flow rate affects Ea significantly (p<0.05). The study showed that the highest Ea of 29% and 27% obtained from L2 and Q1. Ea increased as the furrow length and flow rate increased upto 30m and 0.67l/s respectively. Flow rate influences water productivity significantly (p<0.05). The range of water productivity for both furrow length and flow rate was 0.41 to 0.45 Kg/$m^3$. Based on the result of this finding, potato belete variety resulted in maximum yield at combination 30m furrow length and 0.89l/s flow rate (L2Q1) on sandy clay loam soil.

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