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# The Impact of Alternate Furrow Irrigation on Water Productivity and Yield of Potato at Small Scale Irrigation, Ejere District, West Shoa, Ethiopia

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## Abstract

Alternate furrow irrigation versus every furrow, fixed furrow and farmer practice (open- ended and unstructured furrow) were evaluated at full crop water requirement. The experimental design used was randomized complete block design with four treatment replicated five times. Results obtained revealed that average water application efficiency of alternate furrow irrigation was 67% which was high as compared to other irrigation methods at all irrigation events. Average application efficiencies of ever furrow irrigation, fixed furrow irrigation and farmer practice were 52%, 61% and 34.4% respectively. The average distribution uniformity of alternate furrow irrigation and every furrow irrigation methods were 89.3% and 85.3% respectively, which showed no significant difference between the two methods. However, average distribution uniformity of fixed furrow irrigation was 75.4%, which showed significant difference between alternate furrow and fixed furrow irrigation methods. Alternate furrow irrigation method produced total tuber yield of 33198 kg/ha which showed insignificant difference as compared with that obtained under every furrow irrigation (33369 kg/ha). Total tuber yield harvested from fixed furrow irrigation and farmer practice were 30177 kg/ha and 30098 kg/ha respectively, which showed insignificant difference between the two methods. High marketable yield of 32667.8 kg/ha was recorded from alternate furrow irrigation. Water productivity of 11.2 kg/m$^3$, 10.7 kg/m$^3$, 6.1 kg/m$^3$ and 4.1 kg/m$^3$ were produced under alternate furrow, fixed furrow, and every furrow and farmer practice respectively. It was found that alternate furrow irrigation method saved 50% of water as compared with every furrow and 68.4% as compared with farmer practice. Therefore, it is recommended alternate furrow irrigation method with appropriate irrigation interval is suitable irrigation method; for humid climate where soil is dominated by clay soil and water is liming factor for potato crop production.

**Keywords:** Alternate furrow; Water productivity; Tuber yield

## Introduction

In almost all regions of the world, water supply is the main constraint to crop production due to water demand for rapid industrialization and high population growth. Water is increasingly recognized as a major component in economic development and poverty reduction. According to Rockstrom, et al. holding the current rates of agricultural water use efficiency constant, an estimated additional amount of 5700 km$^3$ of fresh water will be required annually to meet the estimated food demand in 2050 [1]. Agriculture is the largest freshwater user on the planet, consuming more than two thirds of total withdrawals [2]. Production of potato (Solanum tuberosum L.) takes a very important place in the world agriculture, with a production potential of about 381 million tons harvested and 19.3 million hectare planted area [3]. In Ethiopia, potato is grown in four major areas: the central, the eastern, the north western and the southern. In the central area, potato production includes the highland areas surrounding the capital, i.e. Addis Abeba, within a 100–150 km radius.

In this area potato growing zones are West Shewa and North Shewa. About 10% of the potato farmers are located in this area [4]. Early studies have shown that water is the most important limiting factor for potato production and it is possible to increase production level by well-scheduled irrigation programs throughout the growing season [5].

Almost all of the irrigation schemes of west Shoa zone, the western part of Ethiopia, are small scale and traditional. Farmers seem to have awareness about the benefits of irrigation and proven ability to organize themselves to manage small scale irrigation systems. However, it lacks scientific management; they either over or under irrigate their fields. At present situation water is a scarce resource due to use of water for different purposes. However, attention given to agricultural water management by the irrigators as well as the irrigation experts is very low. Therefore, efforts should be put in a place to develop water saving mechanisms which can minimize water lost during application of irrigation water [6].

If the amount of water lost due to poor water application method can be saved, irrigation command area of the scheme can be increased and accommodate the increased number of farmers. Saving unproductive losses creates opportunity for optimized use of a limited supply of irrigation water. Improved irrigation scheduling and water application methods are among the means of cutting losses and increasing efficiency.

In order to allocate the scarce water resources among competing users, identifying irrigation method which maximizes crop water productivity using available water is an obligatory work. The competition for freshwater often implies that, water for irrigation is not always available in the required quantity. Therefore, farmers often have to manage irrigation under moderate or severe water shortage. This experiment is, therefore proposed and executed with the hypothesis that irrigating alternate furrows, i.e., partial wetting of the root system alternatively could save water thereby increasing water productivity (WP) without causing a substantial drop in the yield of potato crop.

As a general objective; this research was planned and implemented to study the impact of alternate furrow irrigation (AFI) on potato yield and water productivity so as to get additional land and sustainable crop and water productivity. Therefore, this study specifically aims at (i) to evaluate the effects of different water application methods on yield and water productivity on farmers' field. (ii) To quantify the amount of water saved under each water application methods.

# Materials and Methods

## Treatments and experimental design

The experiment included three irrigation methods: alternate (AFI), every furrow (EFI) and fixed furrow irrigation (FFI) irrigation methods all were block-ended furrow and farmer practice (making furrow with opened). Farmers around the study area are using irrigation water during dry season for crop production especially horticultural crops such as potato, onion and garlic etc. After land was prepared potatoes are planted on the ridge of furrow with open-ended. Every furrow irrigation (EFI) in which water was applied to every furrow, fixed furrow irrigation (FFI) in which water was applied as fixed every-other furrow throughout the growth season, alternate furrow irrigation (AFI) which is similar to fixed furrow irrigation (FFI), but water was applied to the furrow which was dry in the previous irrigation cycle.

In alternate furrow irrigation (AFI) odd furrows (1, 3, 5 and 7) received water at first irrigation event and even furrows received water at next irrigation (2, 4, 6 and 8) throughout growing season with determined irrigation interval. In fixed furrow irrigation (FFI) water was applied to odd furrows (1, 3, 5 and 7) throughout the growth season with determined irrigation interval and farmer practice which is similar to every furrow irrigation (EFI) but furrows were made by farmer, not tide at the end and was irrigated with farmers irrigation interval.

These treatments were assigned in Randomized Complete Block Design (RCBD) with five replications. The size of each experimental plot was 6 m x 10 m. The experimental field was 27 m by 54 m and occupied a total area of 1458 $m^2$. A spacing of 75 cm between rows (furrows) and 30 cm between plants was used based on recommendation provided by [7,8]. Each experimental plot consists of eight furrows and seven ridges with furrow length of 10 m each.

## Crop characterization

The test crop used in this study was potato (Solanum tuberosum L.) crop. Gudane improved variety was used as test crop having growing period of 120 days. Potato tubers were planted by hand in plot sizes of 6 m by 10 m. Hence, there were a total of 8 rows within a plot and 33 potato tubers within a single row. The spacing of 1m between plots within a block and 1 m between blocks were used. The spacing used between within a single row and between rows within a single plot were collected from Holeta Agricultural Research Center, Horticultural crop research team and other references [7,8].

## Furrow parameters

The most important factors for furrow irrigation are furrow distance, length and slope, and ridge uniformity. Furrow design is an iterative process that should consider the shape of the furrow, the spacing between furrows and furrow length with other factors such as the stream size to be applied and its application time, the soil type and the slope. In potato, the distance between irrigation furrows varies from 60 to 90 cm depending on soil texture. In sandy soil, water leaks away rapid and does not reach far; distance between rows should be smaller than in clay soils. In coarse sandy soils the distance between the furrows should preferably be around 60-65 cm, and in heavier clay soils around 70-80 cm. The spacing between furrows depends on the water movement in the soil type of soil texture and agronomic requirements. In addition, spacing of furrow depends on the type of equipment used in the construction of furrows [9]. Since the textural class of the soil on the study area is clay, spacing of 0.75 m ridges of furrow had been used based on soil texture and agronomic recommendations.

Maximum furrow length depends on slope of the furrows, soil type and depth of water in the furrow. Water should not exceed half ridge height to avoid excess moisture in tuber region. Furrow slope should be not exceeding 0.5% to control erosion. Beyond this there is a major risk of soil erosion following a breach in the furrow system. Soil type also affects furrow length. In sandy soils water infiltrates rapidly, whereas in clay water infiltrates slowly.

The shape of the furrow depends on the soil type and the stream size. Soils with low infiltration rates have usually shallow wide parabolic or U-shaped furrows to reduce water velocity and to obtain a large wetted perimeter to encourage infiltration. Clay soils use a wide, shallow furrow to achieve a large wetted area so as to promote infiltrations [10]. On the other hand, soil with a high infiltration rate requires more or less V-shaped furrows to reduce the wetted perimeter through which water infiltrates. U-shaped furrow is widely practiced in the study area because of the nature of the soil found in this area was clay soil with low infiltration rate and it is easy to construct.

## Crop water requirement

CROPWAT version 8.0 was used for this study to determine reference evapotranspiration, crop water requirements and irrigation schedule by utilizing metrological data as an input. For estimation of water irrigation requirements, climatic, crop and soil data have been utilized as an input. The climatic data such as maximum and minimum temperature, humidity and sunshine hours were used by the model to calculate reference evapotranspiration on monthly basis. This calculation has been done by using FAO Penman-Monteith method [11]. The reference evapotranspiration ETo was calculated by FAO Penman-Monteith method, using decision support software–CROPWAT 8.0 developed by FAO.

At pre-plant irrigation water was applied to every furrow in each plot, two days before planting with minimum water. The purpose of this irrigation was to bring the upper 30 cm soil depth to field capacity and create good soil to encourage a full and even plant stand. In this experiment, the reference evapotranspiration (ETo) and crop water requirement (ETc) was estimated from long years climatic data collected from Metrological station of Holeta Agricultural Research Center.

**Table 1:** Climatic data Used for $ET_o$ calculation (1985-2015).

| Month | Min Temp °C | Max Temp °C | Humidity % | Wind speed km/day | Sunshine Hours |
|---|---|---|---|---|---|
| January | 3.4 | 23.4 | 51 | 130 | 8 |
| February | 5 | 23.9 | 50 | 147 | 7.6 |
| March | 6.7 | 24.4 | 51 | 147 | 7.1 |
| April | 7.9 | 23.9 | 56 | 138 | 7 |
| May | 6.8 | 24.4 | 56 | 130 | 6.3 |
| June | 7.7 | 22.4 | 66 | 95 | 5.1 |
| July | 9.1 | 20 | 78 | 104 | 3.4 |
| August | 9.1 | 19.6 | 80 | 95 | 8.1 |
| September | 7.8 | 20.3 | 74 | 104 | 5 |
| October | 4.9 | 21.9 | 57 | 156 | 7.6 |
| November | 2.3 | 22.4 | 52 | 147 | 8.7 |
| December | 1.9 | 22.8 | 51 | 147 | 8.6 |
| Average | 6 | 22.4 | 60 | 128.3 | 6.9 |
| Climatic data displayed on the above table were collected from Holeta Agricultural Research Center starting from 1985 to 2015 for thirty one years. | | | | | |

## Irrigation schedule

In this study irrigation interval in days and depth of application which is expressed in millimeter has been calculated by using CROPWAT version 8.0. Depth of water application was determined by the model and gave gross water required at experimental field by multiplying with each plot area. The root depth is assumed to increase linearly as a function of time, so it is important to consider the root depth at each stage of growth. The adjustment of depth of application at each stage was done by the model itself.

**Figure 1:** Indicated un-irrigated and furrow under irrigation

## Water productivity

Water productivity was determined by dividing tuber yield by total applied irrigation water and is expressed as follows [12]:

$$WP\left(\frac{kg}{m^3}\right) = \frac{Yield\left(\frac{kg}{ha}\right)}{total\ water\ received\left(\frac{m^3}{ha}\right)} \quad (7)$$

WP ($kg/m^3$)=Yield (kg/ha)/total water received ($m^3$/ha)

Where WP water productivity ($kg/m^3$), Yield (kg/ha) and total water received ($m^3$/ha) from planting to harvest and water applied before planting is not included in the total.

## Irrigation performance indicators

The performance of the system is determined by the efficiency of water conveyed to the field from the channel and distributed within the experimental plot. Irrigation performance mainly determined by using conjunctively various parameters because one is not capable to describe whether the irrigation is satisfied the plant water requirements or not. In this case, two parameters were used to estimate irrigation performance: application efficiency and distribution uniformity.

Field application efficiency (AE): Field application efficiency is the ratio of water directly available to the crop to water received at the field inlet. Application efficiency was calculated based on, water application efficiency (AE) as the ratio between the volume of water held in the root zone of the soil profile after the irrigation and the total volume of water applied during the irrigation process [13].

AE (%)=$D_{sz}$/ $D_a$ × 100 (8)

Where $D_{sz}$ depth of water stored in root zone (mm), $D_a$ total depth of water applied to the plot (mm).

Pre and post irrigation soil moisture analysis method was employed for calculating water stored in the crop root zone. The soil samples for moisture content before and after irrigation were taken at three randomly selected points in each plot. The samples were collected at three depths i.e. 0-20, 20-40 and

40-60 cm. The potato crop has maximum root depth of 60 cm; therefore, soil samples were collected down to 60 cm depth. Moisture content of samples was measured on dry weight basis.

The depth of water stored in the root zone was calculated by equation given in the procedure.

$D_s$ (mm)=M.C × Sp.G × $R_z$ (9)

Where: Ds depth of water stored in root zone (mm), M.C moisture content of soil (%), Sp.G specific gravity of soil, Rz depth of root zone of crop (cm).

Distribution uniformity (DU): Distribution uniformity (DU) shows how evenly water is applied throughout the field and it is important in managing water efficiently. Typically, distribution uniformity (DU) is based on the post-irrigation measurement of water depth that infiltrates to the soil because it can be more easily measured and better represents the water available to the crop. A low distribution uniformity (DU) (<60%) indicates that the irrigation water is unevenly distributed, while a high distribution (DU)>80 indicates that the application is relatively uniform over the entire field. The Christiansen Uniformity Coefficient is given as: -

$$CU = \left(1 - \frac{\sum \left|X_i - X\right|}{nX}\right)100 \qquad (10)$$

where CU is Christiansen uniformity coefficient %, $X_i$ the recorded depth of water stored in root zone (mm) at $i^{th}$ point (from gravimetric moisture determination). It is the moisture content after oven dry of each of the soil samples from a plot.

Soil samples prior to the commencement of the irrigation and two days after irrigation at three points from a plot. N is number of points where samples were taken. X is the mean water depth (mm) of water stored in root zone and is determined by:

$$X = \frac{\sum_{xk=0}^{n} X_i}{N} \qquad (11)$$

Distribution uniformity at low quarter (or simply distribution uniformity) (DUlq) is defined as the average water applied in 25% of the area received the least amount of water, regardless of location, divided by the average water applied over the total area.

$$DU_{lq} = 100 \times \frac{LQ}{M} \qquad (12)$$

Where DUlq distribution uniformity at low quarter (or simply distribution uniformity, DU), LQ average low-quarter depth infiltrated (mm) M average depth infiltrated (mm). The moisture content of the soil is taken from each plot at 2 m, 5 m and 8 m starting from the upper end to the lower end for calculations of irrigation uniformity. Soil samples were taken before and after each irrigation events i.e. one day before irrigation and two days after irrigation.

## Data collection

Data collection was performed before the implementation of the experiment, during the implementation of the experiment and after the implementation of the experiment. Data collected before implementation of the experiment and after harvest were climatic data, soil data and yield and yield component data.

Climatic data: Thirty years climatic data of (maximum and minimum temperature, humidity, wind speed and sunshine hour) on monthly base had been collected from Holeta Meteorological Station of Holeta Agricultural Research Center. The climatic data were collected based on monthly bases (air temperature, humidity, wind speed, rain fall and sun shine) to use as input for CROPWAT program for estimation of ETo.

Soil data: The soil samples were collected from experimental site to determine bulk density, soil moisture, field capacity, permanent wilting point, soil texture, pH, OC, OM, CEC, total nitrogen, available phosphorus and exchangeable potassium in laboratory. To determine the bulk density, undisturbed soil samples were taken by core sampler of known volume (100 $cm^3$) that was driven into the soil of up to desired depth. Since bulk density varies considerably spatially, the samples were taken at two different soil depths (0-30 cm and 30-60 cm) of the soil profile and from three locations across the experimental plot. The samples were dried in an oven to determine the dry weight fraction. Then the bulk density was calculated as the ratio of dry weight of the soil to known cylindrical core sampler volume.

$\rho_b = M_s/V_t$ (13)

where $\rho_b$ is bulk density $gcm^3$, $M_s$ mass of solid (gm) and $V_t$ total volume $cm^3$.

Gravimetric method was used to determine the initial moisture content and moisture content before and after irrigation events. Soil samples were collected from each plot at depths of 0-20 cm, 20-40 cm and 40-60 cm of the soil profile. These samples were collected from each plot along the furrow length at 2 m, 5 m and 8 m to get representative soil moisture content of the plot. After weighing the soil sample, it was placed in an oven at 105°C until the constant weight was obtained. After drying, the soil sample was weighed again.

The gravimetric method was used to determine the soil moisture content and calculated as a dry weighed fraction [14].

φm=(Mw-Ms)/Ms (14)

Where φm is soil moisture, Mw is weight of wet soil sample (g) and Ms is weight of dry sample soil (g).

Yield and yield components: Yield data were recorded on plot basis and extrapolated to hectare basis. All parameters were determined and calculated from the middle 6 rows. That is, the gross size of 6 m x 10 m (60 $m^2$) and the net (harvestable) plot area was 4.5 m x 10 m (45 $m^2$). Marketable tuber yield and unmarketable were differentiated based on the fact that marketable tuber yield was tuber yield which was not affected by disease, not deformed and damaged tubers during harvesting. The number of tubers per plant was recorded from 10 plants randomly selected and averaged to get number of tuber per plant at harvest. Maturity of the potato crop was observed when 50% of the plant haulms (vines) showed yellowed or in each plot they show senescence. Diseased, misshaped, damaged tubers during harvest were recorded as unmarketable tuber yield from the middle rows. Total tuber yield (Kgha$^{-1}$) was recorded as the sum of marketable tuber yield and unmarketable tuber yield and calculated as kg per hectare.

## Results of the Study

### Amount of water applied under each treatment

As per the output of the model, the optimum seasonal irrigation requirement was found to be 584.3 mm (5843 m$^3$/ha) for every furrow irrigation method. For the alternate furrow irrigation (AFI) and fixed furrow irrigation (FFI), 292.2 mm (2922 m$^3$/ha) of water was needed throughout the growing season of potato crop. Application of irrigation water according to CROPWAT model was started after twelve days i.e. after the crop is fully geminated. Before germination all experimental plots were irrigated with the same amount of water. Totally eight irrigation events were considered in the experimental site for determination of application efficiency, distribution uniformity, water productivity and water use efficiency excluding irrigation events prior to planting and before germination.

**Table 2:** Details of irrigation during the growing season in the potato grown experiment.

| Treatment | Number of irrigation (number) | Depth of Water Applied (Wd(mm)) |
|---|---|---|
| Every Furrow Irrigation (EFI) | 8 | 584.3 |
| Alternate Furrow Irrigation (AFI) | 8 | 292.2 |
| Fixed Furrow Irrigation (FFI) | 8 | 292.2 |
| Farmer Practice (FP) | 12 | 925.6 |

The number of irrigation events and depth of water applied (Wd) for each treatment are shown in the above table. The alternate furrow and fixed furrow irrigation treatment consumed less water as compared with every furrow irrigation method. The treatment considered as farmer practice was irrigated by farmer himself with twelve number irrigation events.

The amount of water consumed by treatment implemented by farmer (Farmer practice) was calculated from depth of water flowing in the parshall flume located at the entrance of the plot and the time of irrigation. The seasonal amount of water consumed by the alternate furrow irrigation and every furrow irrigation were amounted to 292.2 mm (2922 m$^3$ m$^3$ ha$^{-1}$), and 584.3 mm (5843 m$^3$ ha$^{-1}$) respectively. According to Pereira and Shock for maximum yields, the crop water requirement (CWR) of potato for a 120 to 150 day crop growth is 500 to 700 mm depending on climate [15]. Amount of water applied for every furrow irrigation treatment was agreed with the range of water requirement stated previously.

Based on the fact that alternate furrow and fixed furrow irrigation reduces number of furrow under irrigation and the amount of water applied to these treatments was reduced by half as compared with every furrow irrigation method. Alternate furrow irrigation technique has been fundamentally based on alternatively wetting and drying opposite parts of the ridge of furrows under which the plant root system is thought to be located. Amount of water applied under alternate furrow irrigation was also agrees with conclusion says alternate furrow irrigation is commonly applied as part of a deficit irrigation program because it does not require the application of more than 50–70% of the water used in a fully irrigated furrow (every furrow irrigation method) [16].

On the other hand, alternate furrow irrigation technique recorded lower values of total evapotranspiration as compared with every furrow irrigation technique. This may be due to less evaporation from the dry furrow that was reflected on decreasing total evapotranspiration [17].

The above table indicates that alternate furrow and fixed furrow irrigation techniques saved 50% of irrigation water as compared with every furrow irrigation technique and 68.4% as compared with farmer practice, whereas every furrow irrigation method saved 37% of irrigation water as compared with farmer practice. The lowest depth of water applied ($W_d$) under alternate furrow irrigation method as compared to every furrow irrigation is as a result of great reduction of wetted surface in alternate furrow irrigation; almost half of the soil surface is wetted in alternate furrow irrigation.

This result supports the outcome obtained by Shayannejad and Moharreri that conclude alternate furrow irrigation method which can supply water in a way greatly reduces the amount of wetted surface, which leads to less evapotranspiration and less deep percolation [18].

### Field application efficiency (AE)

The result shows the average values of water application efficiency calculated separately for each irrigation events. Irrigation application efficiencies under every furrow irrigation method where found between 50 to 55% with average of 52% for all irrigation events, whereas values under alternate furrow irrigation method were found between 64 to 68% with average of 67 % for all irrigation events. The result depicted there is significant ($p<0.05$) difference between every furrow and alternate furrow irrigation.

The result shows application efficiency under alternate furrow irrigation method was higher by 15% as compared to every furrow irrigation method under clay loam soil. The wetted perimeter of alternate furrow irrigation is less as compared to every furrow irrigation method. Hence, alternate furrow irrigation method saves a considerable volume of irrigation water.

The results of this study are in close agreement with Rogers and Lamm concluded that furrow irrigation method have wider range of 60-90% [19]. On overall basis, the values of water application efficiency of every furrow irrigation method are within acceptable ranges as described by Martin [20].

As shown from the application efficiencies under fixed furrow irrigation method where found between 59% to 63% with average of 61% for all irrigation events, whereas under alternate furrow irrigation method the average value is 67 %. The result shows that there is no significant ($p<0.05$) difference between alternate furrow and fixed furrow irrigation methods. From the obtained results, one can clearly see that water application efficiency of alternate furrow irrigation method was higher than fixed furrow irrigation by 7% only.

The results of this study are in close agreement with Ebrahimian, et al. conclude that the mean value of application efficiency of alternate furrow irrigation is higher than that of fixed-every furrow in which the drier furrow remains dry throughout the growing season, due to low lateral and more downward water flow is expected in fixed furrow method [21]. As indicated from the application efficiencies under farmer practice where found between 31 to 41% with average of 34% for all irrigation events, whereas the average values of 52, 67 and 61% where observed under every furrow, alternate furrow and fixed furrow irrigation respectively. According to the results there was high significance ($p<0.05$) difference between framer practice and other methods. The result indicated that farmer practice resulted low application efficiency of 34.4% that is lower by 17.6% as compared to that obtained under every furrow irrigation method. In addition, results obtained under farmer practice shows low application efficiency that is lower by 32.6% as compared to alternate furrow irrigation. This shows that there was high significance difference between farmer practice and alternate furrow irrigation method.

## Distribution uniformity

The results shown the average values of coefficient of uniformity (CU) calculated separately for each irrigation events. The highest coefficient of uniformity (CU) was recorded under every furrow irrigation method which is not significantly ($p<0.05$) different from that recorded under alternate furrow irrigation. However, significant ($p <0.05$) difference is observed between alternate furrow and fixed furrow irrigation methods. This may be due to low lateral movement of water in fixed furrow irrigation as compared to alternate furrow irrigation. Low coefficient of uniformity was recorded under farmer practice which shows high significance ($p<0.05$) difference as compared with other methods.

The average value of distribution uniformity obtained under fixed furrow irrigation for all irrigation events was 75.4%, which is lowered 13.9% as compared with alternate furrow irrigation. This supports the outcome obtained by Rodrigues, et al. concludes that the soil water in the irrigated side of alternate furrow irrigation is depleted more effectively than corresponding side in fixed furrow [22]. This indicated that the root system can partially compensate for the increasing limited water availability on the non-irrigated side of alternate furrow irrigation due to an increase in root hydraulic conductivity. This increases distribution uniformity of irrigation water under furrow irrigation. The movement of water between ridges of alternate furrow irrigation is increased to compensate limited water availability on the non- irrigated side that increases distribution uniformity of irrigation water under this method. This also agrees with the outcome obtained by Liu concludes that larger hydraulic gradient in the soil-root interface was observed under alternate furrow irrigation than under fixed furrow irrigation [23].

## Potato tuber yields

The yield collected from each treatment was further differentiated to total yield, marketable yield and unmarketable yields. Table 11 shows average tuber yield in terms of total tuber yield, marketable and unmarketable yield collected from each irrigation methods including farmer practice.

As indicated from the result the difference observed between every furrow and alternate furrow irrigation methods in terms of total tuber yield was statically insignificant at 5% significant level. This shows that, the total tuber yield was nearly the same in both (EFI and AFI) irrigation methods; whereas total depth of water applied under every furrow irrigation was almost double as compared with that of applied under alternate furrow irrigation. Minor yield reduction (171 kg/ha) was observed under alternate furrow irrigation as compared with every furrow irrigation which is less than 1%. This implies that, applying alternate furrow irrigation will not produce significant yield reduction as compared with every furrow irrigation method in terms of total tuber yield. Therefore, by implementing alternative furrow irrigation technique, almost the same tuber yield was obtained comparing with the every furrow irrigation method. This result agreed with outcome obtained by Ahmadi, et al. conclude that alternate furrow irrigation (AFI) or partial root-zone drying (PDI) can increase water productivity with no or minor yield loss [24]. The result also agreed with the outcome reported that alternate furrow irrigation or partial root-zone drying (PDI) saved irrigation water compared to every furrow irrigation while maintaining similar yield with every furrow irrigation.

By comparing total tuber yield observed under farmer with every furrow and alternate furrow irrigation, high significant difference was observed at 5% significant level. The yield reduction obtained under farmers practice were 3271 kg/ha (9.8%), 3100 kg/ha (9.3%), as compared with every furrow and alternate furrow irrigation techniques respectively. This implies that the extra amount of water added under farmer practice shows adverse effect on potato tuber yield. Farmers in the study area commonly uses fixed irrigation scheduling system because of the scarcity of water and high competition to use available water for crop production. However, fixed irrigation scheduling is not appropriate method to meet crop water requirement as per growth stage the crop. This indicates that the amount of water applied under farmer practice is not agreed with crop water requirement needed at each growth stage. The farmers generally lack knowledge on aspects of soil-water-plant relationship and they apply water to the crop regardless of the plant needs. They seem to relate irrigation occurrence to number of days after planting with fixed intervals rather than crop growth stage progress.

This result agrees with outcome obtained by Shock conclude that improper irrigation depth and frequency can substantially reduce yields by increasing the proportion of rough, misshapen tubers [25].

The difference observed between alternate furrow and fixed furrow irrigation in terms of marketable yield may be related to; under fixed furrow irrigation technique only little amount of water was moved laterally towards the un-watered furrows and large portion of water moves down ward due to watering of furrows that received water at all irrigation events and remain dry un-watered furrow throughout the growing season. This affects the size and quality of potato tubers which agrees with the suggestion given by Kaman fixed furrow irrigation lowers quality of tubers as a result of limitation of water to only one side of furrow [26].

Fixed furrow irrigation and farmer practice were resulted low marketable yield of 29587.6kg/ha and 28266.7kg/ha respectively as compared to that obtained under alternate furrow irrigation and every furrow irrigation. Therefore, the study indicated that low marketable yield was recorded at farmer practice this was due to poor water application method that affects the marketability of the tubers. Improper irrigation depth and frequency can substantially reduce yields by increasing the proportion of rough, misshapen tubers that reduce the quality of potato for marketability [25]. In addition, high unmarketable yield (1831.1 kg/ha) was recorded under farmer practice as a result of poor irrigation water management.

## Water Productivity (WP), irrigation water saved and additional area gained

Water Productivity (WP): The amounts of water applied for the potato from planting to harvest over the growing season are given in table 6. Water productivity (WP) based on fresh tuber production was expressed as the ratio of tuber yield at harvest to the water applied. The WP values obtained were similar to those reported for potato by others and were affected by irrigation techniques.

It is clear that by increasing irrigation water application, a decreasing in crop water productivity could be obtained and vice versa.

The higher mean value of water productivity obtained under alternate furrow irrigation was related to lower amount of water applied with uniform lateral movement in crop root zone and minor tuber yield reduction obtained under this method. The reason of having more water productivity (WP) and minor yield reduction for alternate furrow irrigation could be related to better distribution of water in root zone in both sides of the ridge that increases water and fertilizer uptakes by plant. This result indicated that alternate furrow irrigation is appropriate to increase water productivity by allow applying less irrigation water for potato production which supports the outcome obtained by Saeed using alternate furrow irrigation or partial root zone drying (PDI) higher water productivity (WP) and even better fruit quality can be produced [27].

The difference observed in water productivity between alternate and fixed furrow irrigations was statistically significant at 5% significant level. The same amount of irrigation water was applied for alternate furrow and fixed furrow irrigation techniques. However, alternative drying of root zone under alternate furrow irrigation method showed higher water productivity than fixed drying of root zone under fixed furrow irrigation method. This is due to uniform water distribution between ridges in alternate furrow than fixed furrow irrigation. Uniform water distribution between ridges in alternate furrow irrigation method enhanced root growth and improved nutrient uptake of crop which increases the yield than fixed furrow irrigation method. The results of this study are in close agreement with Wang conclude that alternative furrow irrigation enhanced root growth and increased nutrient uptake of the crop [28].

The difference observed in total water productivity (WP) between farmer practice and other irrigation techniques was statistically highly significant. The reduction of water productivity in farmer practice was related with more volume of water added in farmer practice without yield advantage. This indicates that extra amount of water is added to farmer practice plot as a result of improper irrigation depth and fixed schedule system.

## Summary

This experiment was conducted to study the effect of alternate furrow irrigation system by comparing with others irrigation techniques on yield, water productivity and water use efficiency of potato (Solanum tuberosum L.) [29]. This study emphasized on comparison of irrigation methods to identify the irrigation management strategies which could contribute for water saving, increase water productivity and water use efficiency with no or minimum yield reduction in the humid climate of Western Ethiopia particularly West Shoa zone of Oromia region. Results confirmed that irrigation treatments significantly influenced yield, water productivity and water use efficiencies of potato. In order to compare irrigation methods some parameters such as application efficiency, distribution uniformity, tuber yield and water productivity were measured for all irrigation treatments. Highest value of irrigation performance indicators (coefficient of uniformity and distribution uniformity) were obtained under alternate furrow irrigation. From the investigation the highest total tuber yield was observed under every furrow irrigation method which showed little difference as compared with alternate furrow irrigation. The yield reduction observed under alternate furrow irrigation is less than 1 % as compared with every furrow irrigation method, which has no significant impact on marketable yield of the potato crop. The highest marketable yield (32682.7 $kgha^{-1}$) was obtained from alternate furrow irrigation, whereas the lowest marketable yield (28333.3kgha$^{-1}$) was obtained from farmer practice.

Comparing the results of the irrigation methods from the point of crop water productivity, it clearly confirmed that, alternate furrow irrigation method had more beneficial use of water followed by fixed furrow irrigation and every furrow irrigation methods respectively. The highest water productivity (WP) value (11.2kg m$^{-3}$) was obtained under alternate furrow irrigation (AFI), whereas the lowest value (4.1kg m$^{-3}$) was obtained under famer practice. Alternate furrow and fixed furrow irrigation methods saved 50% of water applied under of every furrow irrigation method. However; under fixed furrow irrigation method low water productivity was recorded as compared with alternate furrow irrigation method.

This study advocates that alternate furrow irrigation was substantially saved water than every furrow irrigation method without significant yield reduction which is sufficient to irrigate additional area of potato cropped land. Moreover, alternate furrow irrigation method increased the benefit-cost ratio (BCR), net return (NR) in addition to saving water.

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