Maximizing Water Productivity of Maize using Alternate Furrow Irrigation at Clay-loam Soil, Raya valley, Ethiopia

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Nowadays, water availability is a major limiting factor for development of agriculture in arid and semi-arid areas. Under conditions of scarce water supply and drought, irrigation practices demand the maximum use of every drop of water to maximize water productivity for irrigated crops. A field experiment with a split-plot design was carried out to evaluate the combined effect of three furrow irrigation techniques and three irrigation levels treatments on maize grain yield and water productivity at Mekhoni Agricultural Research center (MeARC), Raya valley district. Irrigation was applied through furrows in three ways as the main plots: conventional furrow irrigation (CFI), alternate furrow irrigation (AFI), and fixed furrow irrigation (FFI). In CFI, irrigation was applied to every furrow at each irrigation event; in AFI irrigation was applied to alternate furrows which were dry in the preceding irrigation cycle, while in FFI, irrigation was applied to fixed furrows throughout the growing season. Each irrigation technique was further divided into three sub-irrigation treatments: two deficit irrigation levels 75% and 50% ETc and a control of 100% ETc as sub-plot were investigated. Results showed that maximum water productivity was obtained under the AFI system without a trade-off in grain yield and considerably save water. Hence, it is recommended as efficient irrigation technique in areas with limited water resources.

Key words: Alternate furrow irrigation, irrigation level, Maize and Water productivity.

INTRODUCTION

Agriculture faces two major challenges in the 21st century and even in the future: the expansion of irrigated agriculture with poor water use efficiency to feed the ever increasing population on one hand and the increasing competition for water due to the development of other water use sectors on the other hand (Falkenmark and Rockstorm, 2004; FAO, 2017). The water scarcity is also further worsened by climate change. Under such circumstances crop production demand, the maximum use of every drop of water. This requires an increase in water productivity (WP), which is an indicator of production level per unit volume of water. In the agricultural sector there is an urgent need to use available water resources efficiently and enhancing water productivity. This goal will be realistic only if appropriate strategies are found for water savings and for more efficient water uses in agriculture. One important strategy is to increase the productivity of water (Molden et al., 2001). Increasing water productivity means using less water to complete a particular task, or using the same amount of water, but producing more (Descheemaeker et al., 2013). Improving water productivity requires that more value be obtained from the water that will be used for the crops.

In the study area, maize (Zea Mays L.) is one of the important and highly demanded food crops cultivated by furrow irrigation with the highest average grain yield per hectare. With the dire need to improve Raya valley’s overall food security and food self-sufficiency, the production of maize is being promoted. The maize crop variety “Melkassa-II” is suitable for moisture stress areas.

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which is good disease tolerance, economically important and food security crop (Worku et al., 2012). Maize is mainly grown in a wide range of soils under rainfed conditions. Under erratic and low rainfall, a rather deep soil with good water holding capacity is required. It has a deep root system (1 to 1.2 m), thus, soil water can be extracted up to great depths. Maize is particularly sensitive to boron deficiency (Lordkaew et al., 2010).

The term water productivity (WP) is defined by Cai and Rosegrant (2003) as the relationship between crop yield per cubic meter of water consumption, including 'green' water (effective rainfall) for rain-fed areas and both 'green' water and 'blue' water (diverted water from water systems) for irrigated areas. Water productivity with dimensions of kg m$^{-3}$ is a useful indicator for quantifying the impact of irrigation scheduling decisions with regard to water management. Similarly, water productivity (WP) is a quantitative term used to define the relationship between the crop produced and the amount of water involved in the crop production, and is defined as the amount of crop produced per volume of water applied (Elshiekh, 2015; Molden et al., 2010). WP is estimated from the amount of water directly consumed by the agricultural system that is, evaporation and transpiration, not simply the amount of water supplied. While it was used primarily to evaluate the function of irrigation systems as 'more crop per drop' approach in the evaluation of deficit irrigation (DI) strategies it seems useful to extend the concept to include other types of livelihood support, such as mixed cropping, pasture, fisheries or forests (Cook et al., 2006).

Traditionally, agricultural research has focused primarily on maximizing total production. However, in recent years, focus has shifted to the limiting factors in production systems, notably the availability of either land or water. Within this context, DI (irrigation application below the full evapotranspiration) has been widely investigated for maximizing water productivity as a valuable strategy for dry regions (Fereres and Soriano, 2007; Ket, 2019) where water is the limiting factor in crop cultivation.

Nowadays, many water conservation techniques are implemented to improve water productivity, such as partial irrigation, drip irrigation and deficit irrigation. Moreover, water productivity can be improved by increasing yield per unit of the land area using a better crop variety, reducing unproductive water losses and improved agronomic practices, or by growing the crop during the most suitable period (Rockstrom and Barron, 2007). Thus, water productivity can be achieved by factors other than water management without reducing crop yield. Water productivity might be increased with a small reduction in grain yield although the total biomass might be reduced with less irrigation. Higher productivity does not necessarily mean that the crop effectively uses a higher proportion of the water input. For this reason, maximizing water productivity alone would not be particularly useful in identifying water-saving opportunities of the system under consideration.

Water is the most limiting resource for improving agricultural production in northern Ethiopia particularly where this research was conducted, i.e. Raya valley. Besides, now a day's problems of irrigation water management lead to shortage of water and competitions among different agricultural and non-agricultural demands. Moreover, the farmers applied large amounts of water over an extended period of time whithout considering irrigation schedule. With respect to this the need of suitable water resource management is, therefore, serious concern for maximizing water productivity and call the attention for very efficient use of irrigation water among different sectors in the area, where furrow irrigated cropping is the standard practice. In addition, under such circumstance, proper use of furrow irrigation techniques and scheduling of irrigation is one of the key practices in irrigated agriculture to maximize irrigation efficiencies, enhanced crop yield and crop water productivity with smaller initial investment.

Now a days, due to the progress of science and the importance of efficient use of irrigation water for agriculture, various irrigation equipments and methods have been devised to increase water productivity. Previous studies have been conducted to study the water productivity for different crops under various water supply levels (Ali et al., 2007; Elshiekh, 2015; Vazifedoust et al., 2008; Zhang, 2003). Hence, in this study considering scarcity of irrigation water in Raya valley alternate furrow irrigation (AFI) technique, in which the furrows are irrigated alternatively is one of the newly designed and scientifically tested irrigation method for maize production and to increase water productivity with low cultivation cost with the objectives of (1) investigating the effect of alternate furrow irrigation system on maximizing water productivity (2) identifying the interaction and main effect of alternate furrow irrigation technique and deficit irrigation level on yield and water productivity of maize crop.

MATERIALS AND METHODS

Site Description

Practical field data for this study were collected in 2018 from Mekhoni Agricultural Research Center (MeARC) Fachagama experimental site located in Raya valley, Northern Ethiopia. The experimental site is located at 12°41'50"N latitude and 39°42'08"E longitude at an altitude of 1578 m above sea level. From the hydrological point of view, the site is located within the Afar drainage basin. It is 68Kms north of Addis Ababa and about 128Kms south of Mekelle, the capital of the National Regional State of Tigray.

Soil particle size distribution was determined at Mekelle University Soil Laboratory by Boycouos hydrometer method and it was assigned to a textural class based on the mass ratio of the three particles (clay, silt and sand).
with the help of the soil textural triangle of the United States Department of Agriculture (USDA, 2008). Hence, soil at the experimental site is classified as clay-loam textural class (36.5% sand, 36.0% clay and 27.5% silt) which consisted of Vertisols and Fluvisols soil types dominantly. The pH of the soil was also found as 7.77. The average soil water retention capacity or volumetric water content values for a 1m soil profile depth field capacity (FC) and permanent wilting point (PWP) during the study period were found as 37.57% and 21.61%, respectively with an average bulk density of 1.16 g cm\(^{-3}\). Thus, the total available soil water holding capacity (WHC) of the experimental site was determined as 185.57 mm per unit meter of the soil profile. WHC was determined by the difference between the water content at FC and PWP.

The average monthly weather conditions of the study area which were collected on daily basis from Velley verd foods P.L.C. automatic weather station located about 1.5 km away east of the experimental site during the study period are shown in Table 1. The climate of the area is characterized as semi-arid climate region and hot almost throughout the year, except the cooler short winter season (November and December). The mean monthly minimum and maximum temperatures during the study period were 14.45\(^{\circ}\)C and 30.2\(^{\circ}\)C, respectively. The study area has unevenly distributed and erratic annual rainfall amount which ranges between 450 and 600 mm (RVLZ, 2007), with most of the rain falling in July-August. Therefore, maximizing water productivity using deficit irrigation was necessary for crop production in the area. Relatively warmer conditions were prevailed in the month of March which is usually a month with the peak reference evapotranspiration (ETo) value for the study area. Daily potential or reference evapotranspiration (ETo) was estimated using CROWAT software version 8.0.

**Table 1.** Average daily values of metrological statistic during the experimental study

<table>
<thead>
<tr>
<th>Month</th>
<th>(T_{\text{min}}) (^\circ)C</th>
<th>(T_{\text{max}}) (^\circ)C</th>
<th>RH (%)</th>
<th>SH (hrs)</th>
<th>(U_{2}) (km day(^{-1}))</th>
<th>ETo (mm day(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>14.7</td>
<td>30.3</td>
<td>47.1</td>
<td>8.9</td>
<td>134.1</td>
<td>4.47</td>
</tr>
<tr>
<td>February</td>
<td>15.0</td>
<td>30.7</td>
<td>48.0</td>
<td>8.5</td>
<td>138.0</td>
<td>4.83</td>
</tr>
<tr>
<td>March</td>
<td>14.9</td>
<td>31.8</td>
<td>52.2</td>
<td>8.2</td>
<td>127.3</td>
<td>5.0</td>
</tr>
<tr>
<td>April</td>
<td>13.2</td>
<td>27.9</td>
<td>51.0</td>
<td>8.3</td>
<td>121.4</td>
<td>4.82</td>
</tr>
<tr>
<td>Average</td>
<td>14.45</td>
<td>30.2</td>
<td>49.58</td>
<td>8.45</td>
<td>130.2</td>
<td>4.78</td>
</tr>
</tbody>
</table>

Where, minimum air temperature (\(T_{\text{min}}\)), maximum air temperature (\(T_{\text{max}}\)), relative humidity (RH), sunshine hours (SH), wind speed at 2-m height (\(U_{2}\)), and grass reference evapotranspiration (ETo) for the month of January – April at Raya Azebo woreda (MeARC), during 2018 growing season.

**Experimental Layout and Irrigation Treatments**

The experimental design followed was a split-plot design with three replications. The treatment variation was based on irrigation techniques, irrigation levels and/or their interactions with the maize “Melkassa-II variety”. Hence, the experimental treatments consisted in: three furrow irrigation techniques Viz., alternate furrow (AF), fixed furrow (FF), and conventional furrow (CF) as the main plots and three levels of irrigation: 100%ETc, 75%ETc, and 50%ETc were applied in subplots as sub-treatments at each irrigation techniques. Thus, the field experiment had a total of nine irrigation treatment (T) combinations: AF @ 100% ETc (T1), AF @ 75% ETc (T2), AF @ 50% ETc (T3), FF @ 100% ETc (T4), FF @ 75%ETc (T5), FF @ 50% ETc (T6), CF @ 100% ETc (T7), CF @ 75% ETc (T8), CF @ 50% ETc (T9).

The CFI at 100%ETc treatment was considered as full irrigation or control treatment while the other treatments were considered as deficit irrigations. No treatment included zero amounts of irrigation and the treatment variation was based on the furrow irrigation techniques and the amount of irrigation water applied irrespective of maize phenological growth stage. Treatment 1, treatment 4 and treatment 9 were stressed by one-half (50%deficit) than the full irrigation. The area of each main plot was kept at 17.5 m \(\times\) 4.5 m and a sub plot size of 4.5 m by 4.5 m to accommodate six furrows with spacing of 75 cm between rows were used. A buffer zone spacing of 3 m was provided between main plots as well as the replications, while 2 m distance was used between subplots to minimize lateral water movement to adjacent plots.

After the soil or furrow preparation, the soil water content reached near the field capacity before the sowing. An early maturing seed of maize (“Melkassa-II variety”) were sown on 1\(^{\text{st}}\) January, 2018 at a spacing of 75 cm between rows and 25 cm between plants. Standard cultural practices were adopted during the crop-growing season. Based on soil analysis maize plots were uniformly fertilized with triple superphosphate at a rate of 46 kg ha\(^{-1}\) P\(_2\)O\(_5\) before seeding and 130 kg ha\(^{-1}\) urea in two splits, ½ at planting and ½ when the plants reached knee height. Top dressing of N was applied to every furrow in CFI and to the irrigated furrows in FFI and AFI. Weeding was done manually five times before harvesting. Maize was harvested on 21\(^{\text{st}}\) May, 2018.

**Irrigation Water Application Procedure**

In Raya valley irrigation scheme the farmers irrigate their crops depending on their observations and rotations among the users. This caused the farmers tend to over-irrigate their crops beyond the field capacity, which reduces water productivity and net income. In this study three furrow irrigation techniques and three irrigation levels were used to irrigate the experimental field plots to increase water productivity. The source of water for the study was pumped from groundwater and was flowed through closed pipe to the experimental field. Before planting, the experimental plot was uniformly pre-irrigated to maintain the soil moisture at field capacity.
The first and second irrigation events were similar in all irrigation treatments (a total amount of about 90 mm) to ensure optimum germination and vegetation stands. i.e. light irrigations were applied prior to starting treatment applications after planting until the plants reached the established stage and to allow the crops to be established before being subjected to moisture stress. Treatment management of irrigation water application began from maize three leaf growth stage. Irrigation was initiated for all plots whenever the soil moisture content in the control treatment was depleted by 55%. That is, in the deficit-irrigated treatments irrigation occurred on the same day as the fully irrigated plots, but the duration of irrigation application was reduced to obtain the predefined water depths. All the treatments were watered on the same day.

Irrigation water was applied through furrows in three ways as the main plots: conventional furrow irrigation (CFI), alternate furrow irrigation (AFI), and fixed furrow irrigation (FFI). In CFI, irrigation water was applied to every furrow at each irrigation event; in AFI irrigation water was applied to alternate furrows which were dry in the preceding irrigation cycle, while in FFI irrigation water was applied to fixed furrows throughout the growing season or one of the adjacent furrows receives water in fixed form.

Based on the pre-prepared irrigation schedule, the amount of irrigation water was allowed into the plot and/or each furrow for the calculated time and volume as required. Immediately after the desired depth of water applied, plots were closed with the channel banks to stop water from entering the plots. 60% irrigation application efficiency was adopted. The total irrigation water applied over the season at each irrigation event for each treatment to achieve field capacity was recorded. All irrigations in the field were applied with a pre-measured flow from motor pump. An average time of 2.8 minutes was used to apply the desired depth of water into each plot. The time required to irrigate the field plot to a required irrigation depth was calculated as:

\[ t = \frac{AD}{Q} \]  

where \( Q \) is discharge (\( m^3 \) min\(^{-1} \)) from the pipe of irrigation motor pump, \( T \) is time (minutes), \( A \) is area of plot (\( m^2 \)) and \( D \) is depth of irrigation (m).

The depths of water applied to satisfy the crop water requirement were based on the daily reference evapotranspiration of the study area. Determination of the reference evapotranspiration (ET\(_0\)) is the most common method to estimate crop water use from the local climatic data and crop coefficient for different crop stages. Hence, the daily reference evapotranspiration was calculated using the FAO-Penman-Monteith method (Allen et al., 1998) using CROWAT software version 8.0. Irrigation scheduling at the site was done using a scheduling spreadsheet that used the calculated daily maize evapotranspiration as input to estimate daily soil water content in the crop root zone. The control treatment plot was monitored before reached the permanent wilting point and used as a reference to apply irrigation water in other treatments. Water applications for full irrigation treatments were based on the estimated crop water requirement calculated over the entire growing season and those deficit treatments imposed less water as planned comprised of 75% and 50% ET\(_c\) of the full irrigation treatment (CFI 100%ET\(_c\)).

The features of irrigation water applied during the experimental year was also analyzed (electrical conductivity: 0.36 dS m\(^{-1}\), pH: 7.58, SAR=4.93 and RSC=3.2meqL\(^{-1}\)) and considering EC (0.36 dS m\(^{-1}\)) classified as class two (C2) indicating medium salinity hazard may be due to groundwater outflow and low alkali hazard according to graphical method of the United States Salinity Laboratory (US Salinity Laboratory, 1954).

**Measurement of Grain Yield and Development of Water Productivity**

In the study, maize grain yield per plot (kg ha\(^{-1}\)) was determined from the grain weight of all maize plants in each net plot area. Thus, only the central four rows of each plot maize plants were used to analyze the effect of the irrigation treatments on grain yield and the remaining two rows were excluded to reduce border effects. The grains were shelled manually and dried, and finally weighed when moisture content reached at 12.5%, then converted to ton per hectare for each treatment. Crop water productivity was also determined as the total grain yield harvested per total crop water used (ET\(_c\)) relation throughout the growing season (Zwart and Bastiaanssen, 2004) as:

\[ CWP = \frac{Y}{ET_c} \]  

where, CWP is crop water productivity (kg m\(^{-3}\)), \( Y \) is crop yield (kg ha\(^{-1}\)) and ET is the seasonal crop water consumption by evapotranspiration (m\(^3\) ha\(^{-1}\)).

**Data Analysis**

For the comparisons of grain yield among treatments the collected data were statistically analyzed using SAS software version 9.0. When treatment effects are significant mean separation using least significant difference (LSD) i.e. Fisher's Protected LSD test at \( P \leq 5\% \) level was employed to compare the differences among the treatment means.

**RESULTS AND DISCUSSION**

**Total Irrigation Water Applied in Each Irrigation Treatments**

Table 2 summarizes the predefined timings of irrigation events and amounts of total water applied to each irrigation treatment.
A total of eleven irrigation events were used for all treatments during the growing season. The average irrigation interval for maize to re-fill the field capacity before crop water stress occurs in the study area reached 12 days. As can be observed from the table, irrigation depths were lower relatively during initial and late growing stages. The large amount of irrigation water was applied on the 7th and 8th irrigation intervals. Regardless of other factors this may be due to high ETo or atmospheric variations, high Kc, crop water up take and longer irrigation intervals (see details in Table 2). The rain events for the entire growing season were very small (two rain events) and only 15.3 mm an effective rainfall were recorded. Hence, the total crop water requirement of maize in the study area was found to be 537.23 mm for the growing periods of 140 days. Hence, by adopting 60% a field application efficiency of irrigation treatment (CFI @ 100%ETc) was found to be 521.93 and 869.89 mm, respectively and no stress occurred.

**Table 2.** Depth of net irrigation applied in each treatments (mm)

<table>
<thead>
<tr>
<th>Irrigation date</th>
<th>Irrigation interval (days)</th>
<th>CFI 100% ETc</th>
<th>CFI 75% ETc</th>
<th>CFI 50% ETc, AFI and FFI 100%ETc</th>
<th>AFI and FFI 75% ETc</th>
<th>AFI and FFI 50%ETc</th>
</tr>
</thead>
<tbody>
<tr>
<td>14/1/2018</td>
<td>14</td>
<td>23.88</td>
<td>17.91</td>
<td>11.94</td>
<td>8.95</td>
<td>5.97</td>
</tr>
<tr>
<td>27/1/2018</td>
<td>13</td>
<td>23.95</td>
<td>17.96</td>
<td>11.97</td>
<td>8.97</td>
<td>5.98</td>
</tr>
<tr>
<td>17/2/2018</td>
<td>11</td>
<td>38.85</td>
<td>29.14</td>
<td>19.43</td>
<td>14.57</td>
<td>9.72</td>
</tr>
<tr>
<td>25/2/2018</td>
<td>08</td>
<td>34.47</td>
<td>25.85</td>
<td>17.24</td>
<td>12.93</td>
<td>8.62</td>
</tr>
<tr>
<td>06/3/2018</td>
<td>09</td>
<td>38.89</td>
<td>29.16</td>
<td>19.44</td>
<td>14.59</td>
<td>9.72</td>
</tr>
<tr>
<td>21/3/2018</td>
<td>15</td>
<td>84.57</td>
<td>63.43</td>
<td>42.29</td>
<td>31.72</td>
<td>21.15</td>
</tr>
<tr>
<td>06/4/2018</td>
<td>16</td>
<td>89.26</td>
<td>66.94</td>
<td>44.63</td>
<td>33.47</td>
<td>22.31</td>
</tr>
<tr>
<td>20/4/2018</td>
<td>14</td>
<td>67.49</td>
<td>50.62</td>
<td>33.74</td>
<td>25.31</td>
<td>16.87</td>
</tr>
<tr>
<td>30/4/2018</td>
<td>10</td>
<td>51.66</td>
<td>38.75</td>
<td>25.83</td>
<td>19.37</td>
<td>12.91</td>
</tr>
<tr>
<td>09/5/2018</td>
<td>09</td>
<td>43.26</td>
<td>32.45</td>
<td>21.63</td>
<td>16.22</td>
<td>10.81</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>521.93</td>
<td>391.45</td>
<td>260.97</td>
<td>195.72</td>
<td>130.48</td>
</tr>
</tbody>
</table>

CFI= Conventional furrow irrigation, AFI = Alternate furrow irrigation and FFI = Fixed furrow irrigation, AFI and/ FFI 100%ETc = AFI at 100% ETc and FFI at 100% ETc.

Based on the full irrigation treatment the amount of irrigation for other treatments was then calculated, and this resulted in large variation in irrigation depth applied. The least (130.48 and 217.47 mm) net and gross irrigation requirement, respectively were also applied for both AF and FF at 50%ETc equally.

**Effect of Irrigation Treatments on Grain Yield**

The interaction effects of the different irrigation treatments on maize grain yield obtained is presented in Table 3. Variance analysis of mean grain yield was showed that the interaction effects of the three furrow irrigation techniques and the three irrigation levels treatments had shown statistically a significant (P ≤ 0.01) impact on grain yield. The results revealed that grain yields decreased as the amount of irrigation water applied decreased especially under fixed furrow irrigation techniques. The highest grain yield of maize (6.32 tons ha⁻¹) was obtained in the fully irrigated treatment (CFI @ 100%ETc), T₇, due to a better environment created and resulted in a better performance of the crop, but this treatment had no statistically significance difference in grain yield with AFI at 100% ETc treatment, T₆, which resulted in 5.89 tons ha⁻¹ with up to 50% reduction in irrigation amount.

**Table 3.** Amount of gross irrigation applied, water saved and grain yield response

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Number of irrigations</th>
<th>Applied water (m³ ha⁻¹)</th>
<th>Water saved (%)</th>
<th>Grain yield obtained (ton ha⁻¹)</th>
<th>Yield penalty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFI 100% ETc</td>
<td>11</td>
<td>8,698.90</td>
<td>0.00</td>
<td>6.32a</td>
<td>0.00</td>
</tr>
<tr>
<td>CFI 75% ETc</td>
<td>11</td>
<td>6,524.20</td>
<td>25.00</td>
<td>4.84b</td>
<td>23.41</td>
</tr>
<tr>
<td>CFI 50% ETc</td>
<td>11</td>
<td>4,349.50</td>
<td>50.00</td>
<td>3.53cd</td>
<td>44.15</td>
</tr>
<tr>
<td>AF I 100%ETc</td>
<td>11</td>
<td>4,349.50</td>
<td>50.00</td>
<td>5.89b</td>
<td>6.96</td>
</tr>
<tr>
<td>AFI 75% ETc</td>
<td>11</td>
<td>3,262.00</td>
<td>62.50</td>
<td>4.64b</td>
<td>26.58</td>
</tr>
<tr>
<td>AFI 50% ETc</td>
<td>11</td>
<td>2,174.70</td>
<td>75.00</td>
<td>3.35de</td>
<td>46.99</td>
</tr>
<tr>
<td>FFI 100% ETc</td>
<td>11</td>
<td>4,349.50</td>
<td>50.00</td>
<td>4.44bc</td>
<td>29.75</td>
</tr>
<tr>
<td>FFI 75% ETc</td>
<td>11</td>
<td>3,262.00</td>
<td>62.50</td>
<td>3.82bc</td>
<td>39.56</td>
</tr>
<tr>
<td>FF 50% ETc</td>
<td>11</td>
<td>2,174.70</td>
<td>75.00</td>
<td>3.12ef</td>
<td>50.63</td>
</tr>
</tbody>
</table>

LSD (0.05) = 0.47

In contrast, imposition of higher water deficit treatment interaction (FFI @ 50% ETo), T₆, resulted in the lowest grain yield (3.12 tons ha⁻¹) and crops in this treatment was more severely stressed and was not adequate to maintain a wet soil profile than the other treatments. Accordingly, the results revealed that the soil moisture deficits of FFI @
50%ETc can adversely affect the activities of reproductive organs such as grains and other grains components. This is because of the high sensitivity of maize to water stress during flowering and pollination stages and may not be a viable irrigation strategy/treatment given the significant reduction in grain yield. The yield of the other treatments also varied between these two treatments.

Results of this research agreed with Tagheinaghdam et al. (2015) who reported as the mean comparison of grain yields showed that the most grain yield contributes to CFI treatment and AFI treatment was in the next rate. However, FFI treatment contributes the lowest grain yield which could be due to the competition of plants for water. Moreover, the result of this practical research showed that AFI at 100% ETc is the most appropriate and an alternate irrigation option when water is a limiting factor during dry season for maize production in dry regions like Raya valley because this technique saves water consumption by 50% compare to control treatment against 6.96% reduction in grain yield.

The study reveals that the AFI technique results in better root development compared to the other techniques. The result also can be used to estimate the range of water use within which deficit irrigation would be more profitable than full irrigation. Hence, practicing of this research and creating a better environment in the semiarid area of Raya valley helps the cultivation of maize crops that increases cultivation area using the water saved and acceptable for farmers with limitations of water for irrigation. Previous studies of Kang et al. (2000) and Nasri et al. (2010) also reported as when less irrigation was applied, the alternate furrow irrigation (AFI) system had the smallest grain yield reduction. In fact, this yield reduction was not statistically significant in the AFI treatments, but substantial and significant with FFI and CFI treatments which agreed with the present result.

Moreover, Mintesinot et al. (2004) also point out that the lowest production cost is found under alternate furrows scientific scheduling, as the amount of labour required during irrigation is 50% less than the other practices. Conversely, the highest cost of production is observed under every furrow-scientific scheduling management. The same author also concludes that where agricultural labour costs are low, every furrow-scientific scheduling is economic. On the other hand, where both water and agricultural labor are limiting, alternate furrows-scientific scheduling can be considered an option. The observation here is that depending on the availability of resource (labour and water), one can decide to use either of the alternate management options to obtain economically reasonable yield.

**Effect of Irrigation Treatments on Crop Water Productivity**

Table 4 demonstrates calculated crop water productivity (CWP) of maize based on yield data and depths of water applied under different irrigation levels and furrow irrigation techniques. Analysis of variance on CWP revealed that the interaction effects of the irrigation treatmentssignificantly (p<0.01) influenced the CWP of maize. As it can be seen from Table 4, estimates of WP range from 1.18 to 2.29 kg/m3. Significantly higher CWP value (2.29 kg m−3) was obtained from AFI with 50%ETc application and had no significant difference with AFI at 75% ETc which resulted in 2.19 kg m-3. In contrast, the interaction effect of CFI with 100%ETc (full irrigation) resulted in lowest CWP (1.18 kg m-3) and had no significance difference with CFI at 75% and 50% ETc interaction.

According to Yazar et al. (2009), globally measured average CWP values for maize ranged from 1.1 kg m-3 to 2.7 kg m-3 which in line with this study. Similar findings have been reported in some studies (Greaves and Wang, 2017; Igbadun et al., 2008). Data from the table show that the interaction effect of AFI with 100%ETc treatment also resulted in 2.13kg m-3 CWP with only 6.96% yield penalty than fully irrigated treatment. The Comparison suggests that increasing the areas irrigated with the water saved would compensate for any yield loss.

### Table 4. Calculated CWP values of maize for each irrigation treatment

<table>
<thead>
<tr>
<th>No.</th>
<th>Irrigation treatment</th>
<th>CWP (kg m⁻³)</th>
<th>Rank on CWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CFI 100% ETc</td>
<td>1.18</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>CFI 75% ETc</td>
<td>1.19</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>CFI 50% ETc</td>
<td>1.28</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>AFI 100%ETc</td>
<td>2.13</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>AFI 75% ETc</td>
<td>2.19</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>AFI 50% ETc</td>
<td>2.29</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>FFI 100% ETc</td>
<td>1.61</td>
<td>6</td>
</tr>
<tr>
<td>8</td>
<td>FFI 75% ETc</td>
<td>1.81</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>FF 50% ETc</td>
<td>2.14</td>
<td>3</td>
</tr>
</tbody>
</table>

The result of this study showed that even though grain yield of maize were higher for CFI with 100% ETc interaction (fully irrigated) treatment, when the mean yield is evaluated in terms of the amount of water used, AFI techniques resulted in higher WP values without significant yield penalty compared to CFI and FFI irrigation techniques and hence it is taken as proper irrigation scheduling and sustainable water management technique. Similar finding has been reported by Mintesinot et al. (2004). Hence, lower crop water productivity was recorded when maize received higher irrigation amount, this agreed that CWP can be enhanced with less water as reported as well by (Elsheikh, 2015). Earlier findings of Ximing and Rosegrant (2001) also concluded that increased WP reveals an increase in management efficiency. Generally, WP values are influenced by crop yield potential, crop environment, irrigation management practice and climatic characteristics of a region.
CONCLUSIONS

Nowadays, water resources are shrinking and worsened by climate change as the sustainable use of water is increasingly a worldwide problem. Under conditions of scarce water supply crop production demand, the maximum use of every drop of water and an increase in water productivity using proper irrigation techniques. If water used properly, the suggested methods can increase both of production and cultivation areas. Therefore, the overall result of this practical research concludes that if the alternate furrow irrigation technique was used, less irrigation amount and low labour cost could maintain statistically the same grain yield of maize as that of full irrigation or conventional furrow irrigation technique, and as a result water productivity for irrigated water was substantially increased. The reduced yield and other irrigation expenses would also be compensated with the water saved by irrigating additional land. Hence, in areas for possible intervention, the findings of our experiment will be important to end users and decision makers.

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