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Effect of Water Application Methods in Furrow Irrigation Along with Different Types of Mulches on Yield and Water Productivity of Maize (Zea mays l.) at Hawassa, Ethiopia

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Abstract
Water has been identified as one of the scarcest inputs, which can severely restrict agricultural production and productivity unless it is carefully conserved and managed**.** A field experiment was conducted under dry season conditions to investigate the effects of mulch types and water application methods in furrow irrigation system on water productivity and yield of maize (Zea maysL.) at Hawassa, Southern Nations Nationalities, and Peoples Regional State of Ethiopia. Three types of furrow irrigation methods (alternate, fixed and conventional) and two mulch types (plastic and straw mulch) and no mulch with three replications were used as two factors to evaluate the yield and yield component including water productivity of maize in split-plot design, in which furrow irrigation methods were used as the main plot together with the three mulching techniques were used as sub-plot. Results indicated that different types of furrow irrigation method had a very highly significant ($p<0.001$) effect on plant height, cob length, cob weight with seed, aboveground biomass, grain yield, and water use efficiency. Types of furrow irrigation method used highly significantly ($p<0.01$) affected thousand seed weight and harvesting index. Moreover, maize growth, yield and yield components including water productivity were highly significantly ($p<0.01$) influenced due to different mulch types used.However, there was no interaction effect due to the two factors studied (furrow irrigation method and mulching type).Significantly a higher growth, yield and yield component of maize was recorded due to conventional furrow irrigation method than alternate and fixed furrow irrigation method. Highest yield was scored (9003.8 kg/ha) from conventional furrow irrigation water management method. However, higher water productivity (2.43kg/m^3) was obtained due to alternate furrow irrigation method. Moreover, higher growth, yield and yield components including water use efficiency were obtained due to plastic mulch than no mulch and straw mulch. Maximum grain yield (8088.9 kg/ha) and water productivity (2.34kg/m^3) obtained at plastic mulch condition , but the partial budget analysis revealed that straw mulch was economically feasible for farmers than plastic mulch for maize at Hawassa area. Therefore the present study suggests that, for maximizing grain yield under no water stress scenario, irrigation of maize with conventional furrow irrigation methods could be used. On the other hand, under limiting irrigation water condition, irrigation of maize could be done with alternate furrow irrigation method with straw mulch application to minimize evaporation loss and maximize water productivity of maize at Hawassa and similar agro-ecology and soil type.
Keywords: water productivity, yield, maize, mulching and furrow irrigation method
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1. INTRODUCTION

The rapid exponential inclination of population growth worldwide in general and in developing countries is forcing the environment to produce more food and cash crop to feed and enhance the economic development of the people. Water is an important factor for agricultural sustainability, financial development and environmental security. Water has been identified as one of the scarce inputs, which can severely restrict agricultural production and productivity unless it is carefully conserved and managed**.** There is a growing recognition that increases in food production will largely have to originate from improved productivity per unit water and soil (Hofwegen van and Svendesen, 2000).

Agriculture is the main water-consuming sector worldwide (Biswas, 1997),which accounts 70 percent of all water withdrawn from aquifers, streams and lakes (FAO, 2011).The global expansion of irrigated areas to feed the ever-increasing population and the limited availability of irrigation water is not balanced at different part of the world. In arid and semi-arid areas where moisture stress is the main challenge for crop production, the spatial and temporal variations exacerbate the problem. Moreover, the design of irrigation schemes does not address the situation of moisture availability for crop and the competition between different sectors. The , main issue for both irrigated as well as rainfed areas is to improve water use efficiency (Baye, 2011). Water use efficiency and agriculture production can be improved by improving soil and water management practices, and growing drought-tolerant and high yielding cultivars.

Mulching is one of the good management practices among all other to improve water use efficiency and crop yield. Mulching material is may be either organic or inorganic material. Most frequently used inorganic mulch is plastic mulch which is effective in order to cultivate earlier produce by controlling weeds and warming the soil (Katherine *et al.,* 2006). Organic mulches such as straw, hay, grass or leaf matter can provide multiple benefits for organic farms. They are capable of suppressing weeds, of regulating soil moisture and soil surface temperatures. They improve overall soil quality by increasing organic matter of the soil, soil porosity, and water holding capacity while also stimulating soil life and increasing nutrient availability (Kuepper *et al*., 2012).

Irrigation is widely practiced in different part of the world and the expansion is alarming especially in developing countries. Therefore, due to the limited water availability for irrigation, there is a need to optimize water application and enhancement of water productivity similar to maximizing the crop yields by improving soil and water management practice like mulch management and different irrigation water application methods (Biswas, 1997).

Improving water productivity in moisture stressed area is a major attention through different water saving technologies like, supplementary irrigation, evaporation minimization techniques like mulching and greenhouse farming, different furrow irrigation managements and other suitable technologies. For selected crops, application of water in such water saving technologies could improve the water productivity without significantly affecting the yield or with minimal tolerable effect on yield in such areas. That is why increasing water productivity in arid and semi-arid regions is vital for the production of more food from saved water. This is important in countries like Ethiopia where irrigation is applied in low efficiency surface irrigation methods.With furrow irrigation methods, moderate to high application efficiency can be obtained if good water management practice is followed and the land is properly prepared. Researchers have used wide spaced furrow irrigation or skipped crop rows as a means to improve water use efficiency in irrigated agriculture (Kang *et al*., 2000). This research therefore, was planned to investigate how much water could save by alternate, furrow irrigation system and type of mulches in maize crop in Hawassa.

Although there are a few studies were investigated in different parts of Ethiopia through the effect of mulching and furrow methods (Meskelu *et al*.,2018;Mlugeta and Kannan, 2015), the combined effects of different water application methods with mulch types on maize (BH546) yield and water productivity for the study area are rarely studied. Thus, filling the gap and providing information to tackle water scarcity problems on the study area is required.

1.1. General Objective

The purpose of this study is, therefore, to identify suitable mulch types and water application methods and their combined effects in furrow irrigation system on water productivity and yield of maize at Hawassa, Ethiopia.

1.2. Specific Objectives

- To evaluate the effect of different mulch types on yield and water productivity of maize,
- To investigate the effect of alternate, fixed and conventional furrow irrigation systems on water productivity and yield of maize, and
- To evaluate the combined effect of different mulch types and furrow irrigation water application methods on water productivity and yield of maize

2. MATERIALS AND METHODS

2.1. Description of the Study Site

The study was conducted at Hawassa research and farm center located at 7°4'N latitude and 38°3' longitude, with an altitude of 1700 m a.s.l, which is found at Hawassa city, the capital of SNNPR state, which is located about 275 km south of Addis Ababa (see Figure 1). The average annual rainfall for the last 30 years is 960 mm while, the average annual minimum and maximum temperatures are 12.90 °C and 27 °C respectively. Sandy clay loam soil textures are the dominant soils of the area, which is classified as Andosol with pH of 7.84. The most commonly cultivated crops in its surrounding areas are Maize (*Zea mays* L.) and Wheat (*Triticum aestivum* L.).

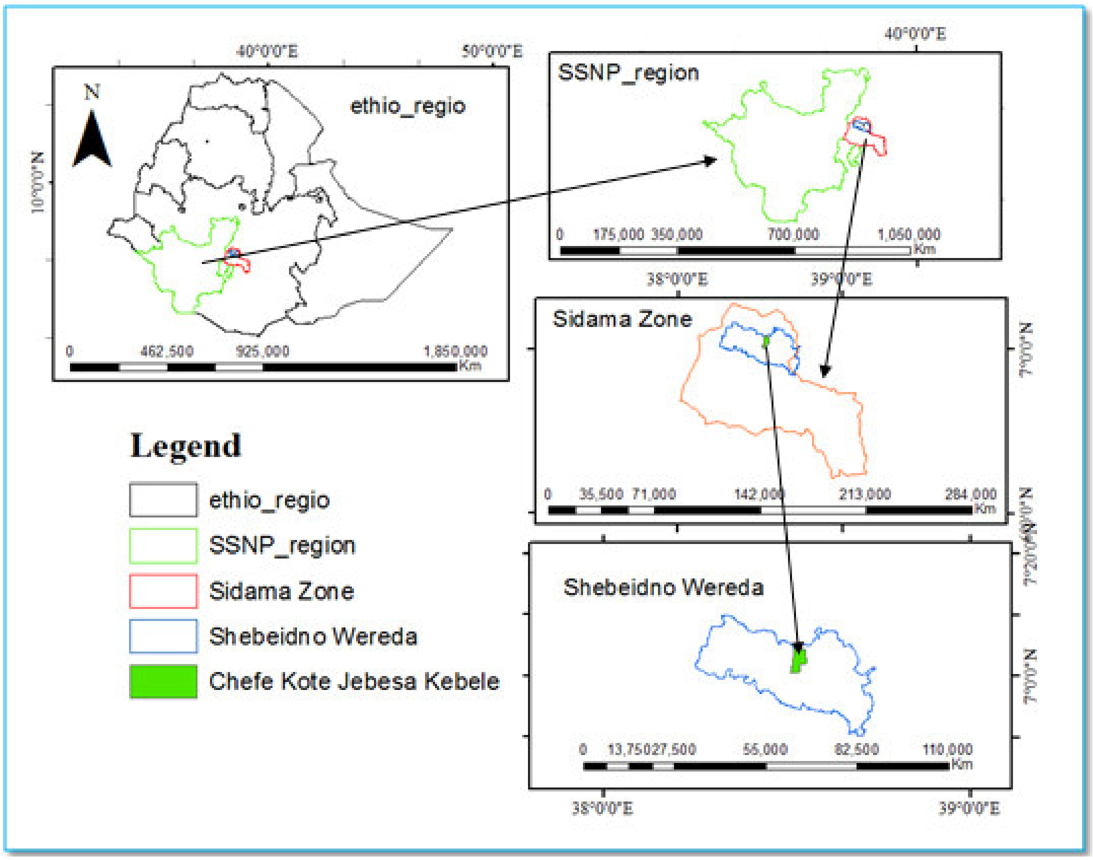

Figure 1: Location map of the study area

2.2. Climatic Characteristics and Rainfall Distribution of the Experimental Site

Based on long-term (1985 – 2015) climatic record of Southern zone National Meteorological Agency, average annual rainfall in the area is 960 mm. The area has two rainy seasons; Short rains occur during Belg (Mar-May) and Meher (Jun-Oct). However the main rainy season can extends from April to September interrupted by some dry spells in June and sometimes in May. The dry season extends from November to February (Fitsum Merkeb, 2016). Most of the total rainfall of the area occurs from mid-June to mid October, with its peak in the month of July and August. (See Table 1).

Table 1:Long-term monthly climatic data of the experimental area

Month	T_{max} (^{O}C)	T_{min} (^{O}C)	RH (%)	Wind speed (m/s)	Sunshine hour (hr)	ETo (mm/day)
January	28.92	11.18	51.82	0.79	9.03	4.02
February	29.90	12.08	50.38	0.80	8.70	4.33
March	29.84	13.03	55.47	0.77	7.90	4.40
April	28.33	14.10	65.20	0.72	6.86	4.05
May	27.25	14.10	69.29	0.81	7.32	3.98
June	25.66	14.26	69.69	1.01	6.65	3.71
July	24.41	14.47	72.90	0.91	4.84	3.23
August	24.83	14.34	72.49	0.84	5.34	3.41
September	25.64	13.70	73.30	0.66	5.77	3.54
October	27.01	12.57	65.16	0.57	7.15	3.76
November	28.26	10.42	54.06	0.64	8.97	3.90
December	28.28	10.46	52.50	0.72	9.34	3.85
Average	27.36	12.89	62.69	0.77	7.32	3.85

Source: Southern Zone National, Meteorological observatory station

2.3. Experimental Design and Procedure

2.3.2. Experimental design.

The furrow methods were in the main plot while mulch treatments were assigned to the sub plots. The mulching rate of 5 t/ha wheat straw (Liu *et al.* ,2010) and white plastic mulch with 30 microns thickness were applied and conventional furrow without mulch was considered as a control for this experiment. The experiment was carried on three replications.

Table 2: The treatment combinations

Main plots	Treatments	Subplots
Conventional Furrow Irrigation	T1	No mulch
	T2	Straw mulch
	T3	Plastic mulch
Fixed Furrow Irrigation	T4	No mulch
	T5	Straw mulch
	T6	Plastic mulch
Alternate Furrow Irrigation	T7	No mulch
	T8	Straw mulch
	T9	Plastic mulch

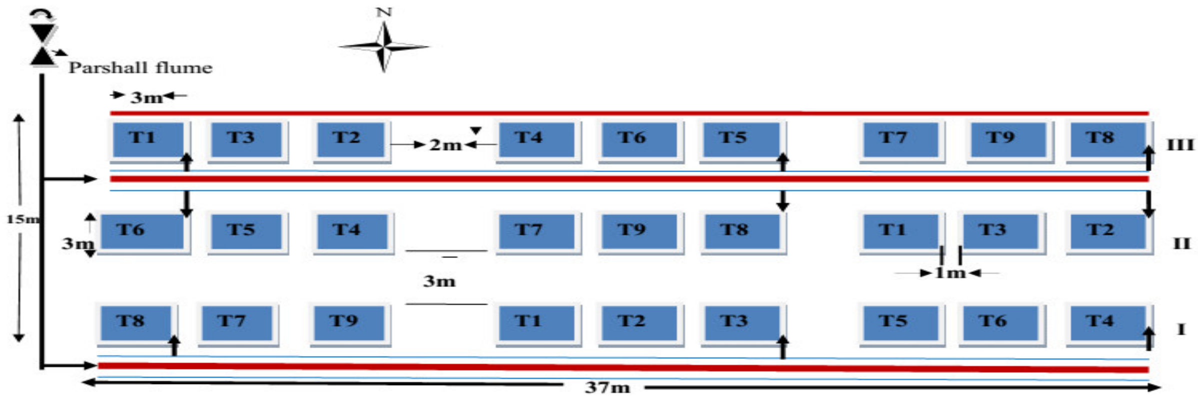

Figure 2: Layout of the experimental plots

2.3.3. Agronomic Operations and Cultural Practice

The amount of irrigation water applied was calculated using CROPWAT 8.0 software by using necessary input data: crop, soil and long term climatic data. Par shall flume of size 3 inch was used to measure the amount of water to be applied for each treatment. Based on the volume of water and the discharge capacity of Parshall flume the time required to irrigate a gives treatment will be calculated for different head available at field condition. Water is then directed to smaller supply channels that feed the furrows. Through careful opening and closure of channel banks, the water was supplied into furrows up to their storage capacity.

2.4. Determination of Soil Physical Properties

2.4.1. Soil texture and bulk density

For textural analysis disturbed soil samples were collected from three depths 0-30 cm, 30-60cm and 60-90 using soil auger at three locations along the diagonal of the experimental block. The core sample volume is known and the oven dry weight was computed divided to volume of core sample to determine the bulk density using the following equation (Jaiswal, 2003)

$$\rho_b = \frac{W_s}{V_c} \quad (1)$$

where: - ρ_b is soil bulk-density (g/cm^3), W_s is mass of dry soil (g) and V_c is volume of soil in the core (cm^3).

2.4.2. Soil moisture determination

The soil sample was collected using soil auger based on the root depth of the crop (0-15cm, 15-30cm, 30-60cm and 60-90cm) for monitoring the moisture content of the soil and oven dried at 105^{0}C until the change in weight is constant. Then the oven-dried sample was weighed to determine the water content of the soil. The water content in the soil was determined in weight base using the following equation (Jaiswal, 2003).

$$\theta_m = \frac{(W_w - W_d)}{W_d} \times 100 \quad (2)$$

where: - θ_m = water content on weight basis (%),
W_d = weight of dry soil (g), and
W_w= weight of wet soil (g).

2.4.3. Field capacity and permanent wilting point

Soil samples for determination of moisture content at field capacity (FC) and permanent wilting point (PWP) from three depths 0-30 cm, 30-60cm and 60-90 cm were collected from three locations of the experimental plot at similar locations where the soil was collected for texture and bulk density (Jaiswal, 2003). The total available water (TAW) was calculated based on the data of FC, PWP and root depth as using the following equation.

$$TAW = 1000 \sum (\theta_{FC} - \theta_{PWP})\, \rho_b * Z_d \quad (4)$$

2.4.4. Infiltration capacity of soil

The soil infiltration capacity was measured using the double ring infiltrometer. Infiltration measurement was made at three random spots and the average value was made to represent the infiltration rate of the experimental site.

2.5 Crop Water and Irrigation Water Requirement

2.5.1. Determination of crop water requirement

Calculation of daily ETo was computed using CropWat model version 8.0 (FAO, 2009) based on the daily climatic data collected at Southern zone National Meteorological Agency. The CropWat model calculates ET_O based on the following formula, which is known as FAO Penman-Monteith equation.

$$ET_O = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T+273}\right) u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (5)$$

Each day evapotranspiration of the crop was determined by multiplying the daily crop coefficient (K_C) of the crop by the daily reference evapotranspiration (ET_O).

$$ET_C = K_C \times ET_O \quad (6)$$

2.5.2. Determination of net irrigation water requirement

Determination of net irrigation water requirement was done based on the water holding capacity of the soil from critical depletion level to field capacity in the effective root depth for 100% ET_C treatment based on the following formula.

$$I_n = (FC - PWP) * P * \rho_d * R_d - R_e \quad (7)$$

2.5.3. Determination of effective rainfall

Determination of effective rainfall was computed based on the following formula of 'dependable rainfall' using daily rainfall data (FAO, 2009).

$P_{eff} = 0.6 * P - 3.33$ for daily precipitation less or equal to 23.3mm (8)

$P_{eff} = 0.8 * P - 8$ for daily precipitation greater than 23.3 mm (9)

2.5.4. Gross irrigation water requirement

For this particular experiment, irrigation efficiency was taken as 60%, which is common for surface irrigation method in furrow irrigation% (Chandrasekaran *et al*.,2010).

$$I_g = \frac{d_n}{e_a} \quad (10)$$

where:-

I_g: gross irrigation (mm)

d_n: net irrigation depth (mm)

e_a: irrigation application efficiency

Volume of water applied for every treatment was determined based by multiplication of plot area and gross irrigation requirement. The irrigation time required to irrigate each treatment was calculated based on the discharge head relation of 3-inch Parshall flume.

2.6. Data Collection

Related agronomic parameters (sowing date, spacing, fertilizer application time, wedding and pesticide application, date of planting, emergence) ,growth, yield and yield components (plant height, cob length, , weight of grain per cob , above ground biomass, straw yield, 1000% seed weight) and water productivity data were collected. These parameters were determined in the following ways:

2.7. Water Productivity (WP)

Water productivity was determined based on the ratio of economical yield of maize (grain yield per hectare) to the net irrigation depth and effective rainfall used from germination to harvest (Chandrasekaran *et al*., 2010).

$$\text{Water productivity}\left(\frac{kg}{m^3}\right) = \frac{\text{Grain yield}\left(\frac{kg}{ha}\right)}{\text{Seasonal net amount of water}\left(\frac{m^3}{ha}\right)} \quad (14)$$

2.8. Economic Analysis

To assess the costs and benefits associated with mulch materials the partial budget technique as described by

CIMMYT (1988) was applied on the yield results. The net income (NI) was calculated by subtracting total variable cost (TVC) from total Return (TR) as follows:

$$\mathrm{NI} = \mathrm{TR} - \mathrm{TVC} \quad (15)$$

2.9. Data Analysis

The collected data were statistically analyzed using statistical analysis system (SAS) version 9.3 (SAS, 2002) for the variance analysis. Mean comparisons were executed using least significant difference (LSD) at 5% probability level. Correlation analysis was also used to see the association of maize growth parameters, yield component, yield and water use efficiency.

3. RESULTS AND DISCUSSION

3.1. Selected Soil Physical Characteristics of the Experimental Plots

Physical soil analysis showed that texture of soil was sandy clay loam and average moisture content on mass base at FC (-0.33 bar) and PWP (-15 bar) were 27% and 15%, respectively. Average volumetric TAW was 142.8 mm/m with a bulk density of 1.19g/cm^3 and readily available water, with optimum depletion level of 55%, was calculated as 78.5 mm/m (see Table 3).

Table 3: Soil physical characteristics of the experimental site

Soil property	Soil depth (cm)			
	0-30	30-60	60-90	Average
Particle size distribution				
Sand (%)	49	48	47	48
Silt (%)	26	26	25	26
Clay (%)	25	26	28	26
Textural class	Sandy clay loam	Sandy Clay loam	Sandy Clay loam	Sandy Clay loam
Bulk density (g/cm^3)	1.16	1.20	1.22	1.19
FC mass base (%)	27.0	26.5	26.0	27.0
PWP mass base (%)	14.6	14.5	14.5	15.0
TAW volume base (mm/m)	143.8	144.0	140.6	143.0

3.2. Selected Chemical Properties of Experimental Plot Prior to the Experiment

Soil pH was found to be at the optimum value (7.84) for maize and other crops. The value of EC (0.18 ds/m) was lower considering the standard rates in the literature (Landon, 1991). Soil salinity was not a problem at the time. Generally, 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. Therefore, the soil of the study area was normal soil. The weighted average organic matter content of the soil was about 3.52%. As cited in Staney and Yerima (1992), the organic matter content of the soil is of medium class. The average value of available nitrogen and phosphorus were found about 0.17 % and 5.51%, respectively (Table 4).

Table 4: Soil chemical characteristics of the experimental site

soil chemical properties	Tested results
pH	7.84
Organic matter content (%)	3.52
Available nitrogen (%)	0.17
Available phosphorus (ppm)	5.51
Electrical conductivity (ds/m)	0.18

3.3. Infiltration Capacity

The data collected at the field from double ring infiltrometer were used to generate the infiltration rate curve as shown in Figure 3. The basic infiltration rate in this experiment was found to be 27 mm/hr, which is within the range of sandy clay loam soil (20 to30) mm/hr (FAO, 1979).

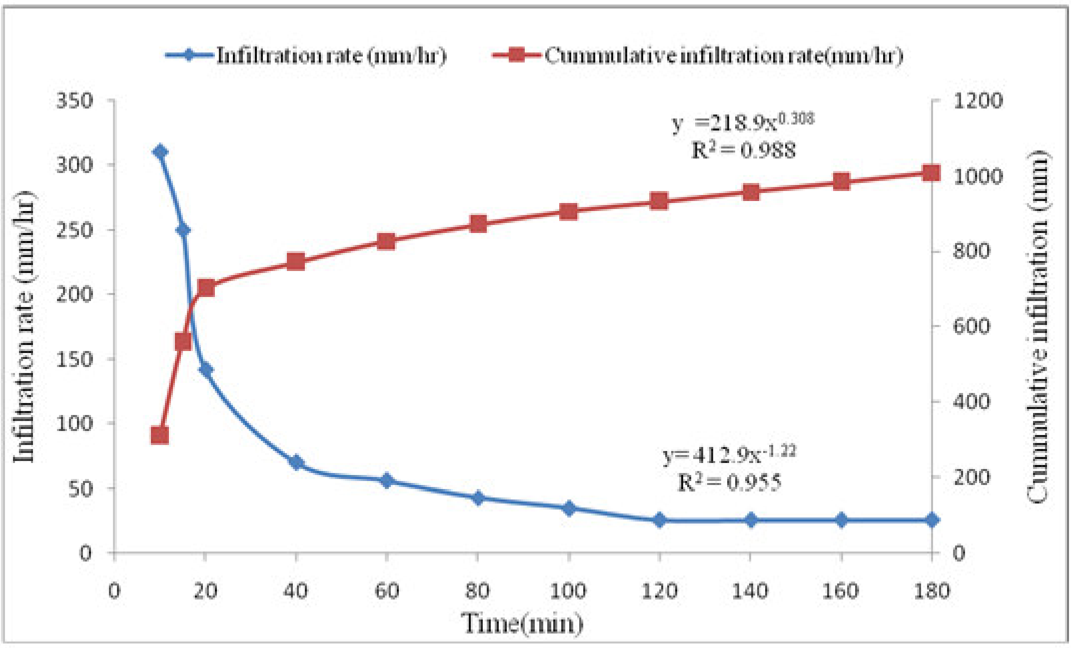

Figure 3: Infiltration capacity of field soil

3.4. Irrigation Water Requirement/Application

The water requirement of maize was computed for the growing season using the CROPWAT 8 program with climate, soil and crop input data from the study area. The average reference evapotranspiration (ETo) of the site was found to be 3.85 mm/day (Table 1). The total available water of the soil was 143 mm (Table 3).The net irrigation requirement was calculated using the CROPWAT 8 Computer program is presented in Table 5.

3.5. Irrigation Water Amount

Table 5: Net and gross irrigation water applied to experimental plot

	Net irrigation water applied(mm)			**Gross irrigation water applied(mm)**		
Date	**CFI**	**AFI**	**FFI**	**CFI**	**AFI**	**FFI**
28-Nov	43.40	21.70	21.70	72.33	36.17	36.17
12-Dec	36.30	18.15	18.15	60.50	30.25	30.25
28-Dec	48.10	24.05	24.05	80.17	40.08	40.08
11-Jan	58.90	29.45	29.45	98.17	49.08	49.08
24-Jan	72.50	36.25	36.25	120.83	60.42	60.42
7-Feb	70.40	35.20	35.20	117.33	58.67	58.67
21-Feb	68.60	34.30	34.30	114.33	57.17	57.17
7-Mar	61.80	30.90	30.90	103.00	51.50	51.50
22-Mar	28.60	14.30	14.30	47.67	23.83	23.83
	488.6	**244.30**	**244.30**	**814.3**	**407.17**	**407.17**

*where CFI=conventional furrow irrigation, AFI=Alternative furrow irrigation and FFI= Fixed furrow irrigation

3.6. Effect of Water Application Methods and Types of Mulches on Growth Components of Maize

3.6.1. Plant height

The analysis of variance revealed that Plant height was highly significantly ($p<0.001$) influenced due to different types of irrigation water management methods and different types of mulch (Table7). Maximum plant height (245.43 cm) was observed for conventional furrow method, whereas the minimum plant height (177.19 cm) was observed at fixed furrow method. The maximum plant height recorded at conventional furrow method was statistically superior to both fixed and alternate furrow methods. On the other hand, the shorter plant height was observed at fixed furrow method and this was statistically not significant with that of an alternate furrow irrigation water management method that attained 182.15cm.

The study also revealed that maximum plant height of 194.16 cm was obtained at plastic mulch. The maximum plant height obtained at plastic mulch was not statistically different from straw mulch condition. On the other hand, the minimum plant height of 179.542 cm was observed at no mulch condition and it was statistically inferior to both straw and plastic mulch condition. The highest plant height observed at conventional furrow had been 38.5% higher than the plant height observed at fixed furrow method. Moreover, plastic mulching improved plant height by 8.1% than no mulching condition. This might be due to highest soil moisture content in the root zone due to higher irrigation depth application in conventional furrow irrigation method than alternate and fixed furrow methods which leads to somehow moisture stress in the later cases. On the other hand, plastic mulching leads to conservation of the available soil moisture through reducing evaporation. These could improve growth condition of maize that leads to increasing plant height.

This coincides with the study of Meskelu *et al*. (2018), Mulugeta and Kannan (2015) and Zelalem (2017) who reported conventional furrow irrigation method leads to the higher yield components and plant height followed by alternate and fixed furrow, respectively. Similar findings were also reported by Dehkordi and Farhadi (2016) and Meskelu *et al*.(2018) who reported that different mulching condition significantly affected plant height and higher growth of maize.

3.6.2. Cob length

The analysis of variance revealed that the different types of irrigation water management methods and different types of mulch highly significantly ($p<0.001$) influenced parameter cob length (Table7). Longest cob length (20.44 cm) was observed at conventional furrow irrigation water application method. The maximum cob length observed at conventional furrow method was statistically superior to both alternate and fixed furrow methods. Contrary to this, shorter cob length (18.16 cm) were observed when irrigation was applied using fixed furrow irrigation method. However, the minimum value recorded was statistically similar with that of alternate furrow method.

Moreover, the result also revealed that cob length was highly significantly affected due to different mulch types used. Longest cob length (20.27 cm) was observed at the plastic mulching condition. The maximum cob length observed at plastic mulching was statistically similar with that of straw mulch. Contrary to this, shorter cob length (17.74 cm) was observed under no mulching condition and minimum cob length observed at no mulching condition was significantly inferior to both plastic and straw mulch.

This might be due to highest soil moisture content in the root zone due to high irrigation water depth in conventional furrow method which leads to favorable growth condition. This coincides with the study of Meskelu. *et al*. (2018), Mulugeta and Kannan, (2015) and Zelalem, (2017) who reported conventional furrow irrigation method leads to the highest yield components such as plant height and cob length followed by an alternate and fixed furrow, respectively. A similar finding was reported by Singh et al. (2016) who reported application of rice straw mulch (6 t/ha) enhanced plant height and yield attributes.

3.6.3. Cob weight with seed

The analysis of variance revealed that highly significant ($p<0.001$) difference was observed on maize cob weight with seed due to different types of irrigation water management methods and different types of mulch during the study season. The higher cob weight with (287g) obtained at conventional furrow method were statistically superior to both alternate and fixed furrow method. The lower cob weight with seed (193 g) was observed at fixed furrow method. Moreover, this was statistically inferior to both conventional and alternative furrow irrigation water management methods

The study also revealed that higher cob weight with seed of 262.28 g obtained at plastic mulch condition and this was statistically superior to both straw mulch and no mulch conditions. Contrary to this, the lower cob weight with seed of 213 g was observed at no mulch condition which was statistically inferior to both plastic and straw mulch conditions. This finding is in line with different past findings on maize (Mulugeta and Kannan, 2015; Zelalem, 2017; Meskelu *et al*., 2018; Diver, Kuepper *et al*., 2012) .

Table 6. Effect of water application methods in furrow irrigation and types of mulches on growth and yield components of maize

Treatments		PH (cm)	CL (cm)	CWWS (gram)
Irrigation type	CF	205.43^{a}	20.44^{a}	287.04^{a}
	AF	182.15^{b}	18.96^{b}	233.74^{b}
	FF	177.19^{b}	18.16^{b}	193.10^{c}
	LSD 0.05	6.86	0.88	18.39
Mulch type	plastic	194.16^{a}	20.27^{a}	262.28^{a}
	straw	191.07^{a}	19.55^{a}	238.60^{b}
	No mulch	179.54^{b}	17.74^{b}	213.00^{c}
	LSD 0.05	6.86	0.88	18.39
	CV (%)	3.60	4.60	7.70

*Means followed by different letters in a column differ significantly and those followed by the same letter are not significantly different at $p<0.05$ level of significance. PH = plant height, CL = cob length and CWWS = cob weight with seed

3.7. Effect of Water Application Methods and Types of Mulches on Yield and yield components of Maize

3.7.1. Aboveground biomass

The different types of furrow irrigation water management methods on maize have shown a very highly significant ($p<0.001$) influence on aboveground biomass production (Table 9). The highest aboveground biomass (47.70 t/ha) was observed at conventional furrow method (100% ET_C).The maximum aboveground biomass obtained at conventional furrow method was statistically superior to both alternate and fixed furrow methods. Contrary to this, minimum aboveground biomass (36.68 t/ha)) was obtained at fixed furrow irrigation method. The minimum aboveground biomass obtained at fixed furrow was statistically similar with that of alternate furrow irrigation method. The highest aboveground biomass of maize obtained at conventional furrow irrigation method lead to an improvement of 30.2 % than the fixed furrow method.

The analysis of variance also revealed that different types of mulch on maize had a highly significant ($p<0.001$) influence on aboveground biomass (Table 9). Maximum aboveground biomass (45.67 t/ha) was observed at the plastic mulching condition. The maximum aboveground biomass obtained at plastic mulching was statistically similar with that of straw mulch condition. Moreover, the minimum (36.40 t/ha) aboveground biomass obtained at no mulching condition was statistically inferior to both treatments. The highest aboveground biomass of maize obtained at plastic mulching lead to an improvement of 25 % over the non-mulching condition.

This might be due to highest soil moisture content in the root zone due to high irrigation water depth in conventional furrow method leads to make a favorable condition for maize physiological and photosynthesis processes. Makino (2011) reported that 90% of plant biomass is obtained from photosynthesis product, in which water is the main component. Guo *et al*. (2013) reported that moisture stress in plants reduces photosynthesis capacity by reducing chlorophyll content and damage of the reaction center of the photosystem. Similar report was reported by Mulugeta and Kannan (2015) on maize in which highest aboveground biomass and grain yield obtained under conventional furrow irrigation with irrigation water application of 100% of crop water requirement than the alternate and fixed furrow irrigation method

3.7.2. Grain yield production

Different types of furrow irrigation water management methods has highly significantly influenced the grain yield of maize per hectare production ($P < 0.001$) from the result obtained highest yield was scored (9003.8 kg/ha) from conventional furrow irrigation water management method and it has a significant difference with alternative furrow irrigation and fixed furrow irrigation water management methods (table 9). Contrary to this, minimum grain yield (5922.3) was obtained at fixed furrow irrigation method. The minimum grain yield obtained at fixed furrow irrigation water management method was statistically similar with that of alternate furrow irrigation method which was attained 6664.4 kg per hectare production.

The highest grain yield of maize obtained at conventional furrow irrigation method lead to an improvement of 52% than the fixed furrow method. Of the water application in alternative furrow irrigation treatments, showed the least effect on yield, while that of water application in fixed furrow irrigation treatments showed the greatest reduction of yield. The reduction of irrigation water from the conventional furrow to fixed furrow water application leads to reduction of grain yield by 52%.

The analysis also revealed that different types of mulch on maize had a highly significant ($p<0.01$) influence on grain yield. Maximum grain yield (8088.9 kg/ha) was observed at plastic mulching condition. The maximum grain yield obtained at plastic mulching condition was statistically similar with that of straw mulching condition (Table 9). Moreover, the minimum (6271.4 kg/ha) grain yield obtained at no mulching condition observed at no mulch condition was significantly inferior to both plastic and straw mulch. The highest grain yield of maize obtained at plastic mulching lead to an improvement of 29% over the conventional non-mulching condition.

The data reveal that, application of plastic and straw mulch lead to an improvement of grain yield production per hectare by 29% and 15.3% respectively. The current finding is in line with Meskelu *et al*. (2018) who reported maize grain yield was increased by 16.9% in black plastic mulch than the non-mulch condition. Moreover, Yaseen et al. (2014) revealed that maximum increase in biomass (29.56%) and grain yield (35.5%) were recorded on mulch and higher irrigation depth treatments.

Even though there is no significant difference among treatments statistically in the interaction , the maximum and minimum mean values were observed from CFI with plastic mulch condition (10119.12 kg/ha) and FFI under no mulch condition (4695.65 kg/ha), respectively. The highest grain yield of maize obtained at conventional furrow irrigation method with plastic mulch condition lead to an improvement of more than 95% over the fixed furrow method with no mulch condition. The current finding is in line with Meskelu, *et al*. (2018).

3.7.3. Seed weight

The analysis of variance revealed that 1000-seed weight was significantly ($p<0.01$) influenced due to different types of furrow irrigation water management methods (Table 9). On the other hand, different mulching type had significant ($p<0.05$) effect on 1000-seed weight. The highest (442.0 g) 1000-seed weight was obtained at conventional furrow method and it was statistically similar with that of alternate furrow method. On the other hand, the minimum (365.3 g) 1000-seed weight was obtained at fixed furrow condition which was statistically inferior to both conventional and alternate furrow method. Moreover, the maximum 1000-seed weight (432.1g) observed at plastic mulching was statistically superior to none mulch condition but statistically in significant effect with straw mulch condition. Contrary to this, 1000-seed weight (381.1g) were observed under no mulching condition. However, the minimum 1000-seed weight observed at no mulching condition was statistically similar with that of straw mulch and inferior to that of plastic mulch condition.

The maximum 1000-seed weight due to conventional furrow irrigation methods was 11.4 % higher than that observed under fixed furrow method. Additionally, application of plastic mulch had an improvement of 1000-seed weight by 12% over no mulch condition (Table 9). Thus as the result reveals, weight is strongly associated with the amount of applied irrigation water as well as the application of mulches.

This study is in lines with Mansouri *et al*. (2010), who reported that when the amount of water increase, both the thousand seed weight and grain yield were increased. Similarly, Meskelu *et al*. (2017) reported the application of lower irrigation depth leads to lighter seed weight on wheat under irrigation. Awal and Khan (2000) reported mulching improves maize growth parameters and yield components.

Table 7. Effect of Water Application Methods in Furrow Irrigation and types of Mulches on yield and yield components of maize

Treatments		**BMPHA (ton/ha)**	**GYPHA (kg/ha)**	**1000SW (gram)**
Irrigation type	CF	47.70[a]	9003.8[a]	442.00[a]
	AF	40.36[b]	6664.4[b]	426.77[a]
	FF	36.68[b]	5922.3[b]	365.33[b]
	LSD 0.05	3.83	931.36	41.92
Mulch type	Plastic	45.67[a]	8088.9[a]	432.13[a]
	Straw	42.67[a]	7230.3[a]	420.86[ab]
	No mulch	36.40[b]	6271.4[b]	381.11[b]
	LSD 0.05	3.83	931.36	41.92
	CV (%)	9.21	12.94	10.19

*Means followed by different letters in a column differ significantly and those followed by the same letter are not significantly different at $p<0.05$ level of significance. BMPHA = above ground biomass per hectare, GYPHA = grain yield per hectare, SYPHA and SW = seed weight

3.8. Effect of Water Application Methods and Types of Mulches on Water Productivity

3.8.1. Water productivity

The different types of furrow irrigation water management methods on maize have shown a very highly significant ($p<0.001$) influence on water productivity (Table 11). Results indicated that the water productivity of maize was higher under alternate furrow irrigation method as compared with conventional and fixed furrow method. Maximum water productivity (2.43kg/m3) observed at alternate furrow method was statistically superior to both conventional and fixed furrow methods. The minimum water productivity (1.64 kg/m3) was observed at conventional furrow method and this was statistically inferior to both alternate and fixed furrow method during growing seasons (Table 11). The irrigation water application method of alternative furrow (50%ETc) gave proportionally higher water productivity compared with conventional furrow (100% ETc). The lower water productivity at 100% ET_C might be attributed to higher irrigation water depth applied, much of which was lost through soil evaporation and deep percolation. The higher amount of irrigation water application associated with lower water use efficiency and lower amount of irrigation water amount associated with higher water use efficiency.

Additionally, different types of mulch highly significantly ($p<0.01$) influenced maize water productivity. Analysis of variance revealed that water productivity was maximized at plastic mulching than straw and no mulch condition. The maximum water productivity (2.34 kg/m3) obtained at plastic mulching was statistically superior to no mulch and had statistically no significant difference with straw mulch conditions. The minimum water productivity (1.80 kg/m3) was observed at no mulch condition was statistically inferior to both straw and plastic mulching at different irrigation water management methods.

The highest water productivity obtained at alternate furrow method was 48% higher than the conventional furrow irrigation method. While the highest water productivity obtained at plastic mulch condition was 30% higher than the control no mulch condition.

Although a non significant ($p<0.05$) interaction effect was observed between irrigation type and mulch type on improving water use efficiency,(Table 12) maximum water use efficiency was observed at plastic mulching when combined with alternate furrow method. The maximum water use efficiency (2.67 kg/m3) obtained at plastic mulching under alternate furrow irrigation method. On the other hand, the minimum water use efficiency (1.48 kg/m3) obtained at conventional furrow irrigation method under no mulch condition.

Different studies conducted on maize reveal water application methods in furrow irrigation and types of mulches affect water productivity of irrigated maize (Elias *et al*., 2018). The study of Kang *et al.* (2000) indicated that AFI had better performance for increasing WUE (2.67 – 5.75kg/m3) relative to alternate furrow irrigation resulted in significant reduction in maize grain yield. Alternate furrow irrigation also increased water use efficiency in the wheat-cotton rotation in Punjab, India (Thind *et al*., 2010). Moreover, application of the alternate furrow irrigation increased water productivity rather than conventional furrow irrigation in sugarcane fields in southern part of Iran (Sheynidashtgol *et al*., 2009). Kang *et al*. (2000) evaluated the alternate furrow irrigation (AFI), fixed furrow irrigation (FFI) and conventional furrow irrigation (CFI) with different irrigation amounts for maize production.

Similarly, different mulching types lead to maximizing water productivity. Xu *et al*. (2015) reported that water use efficiency of maize under plastic mulching (3.27 kg/m3) was increased by 16%compared to the control treatment without mulching, although the overall evapotranspiration was similar between the two treatments. Montazar and Kosari (2007) reported that water use efficiency of different crops including maize could be enhanced though mulching to conserve moisture in the soil for proper utilization by the plant.

Table 8. Effect of water application methods in furrow irrigation and types of mulches on water productivity and harvesting index

Treatments		**WP (kg/m^3)**
Irrigation type	CF	2.16^b
	AF	2.43^a
	FF	1.64^c
	LSD $_{0.05}$	0.26
Mulch type	Plastic	2.34^a
	Straw	2.10^a
	No mulch	1.80^b
	LSD $_{0.05}$	0.26
	CV (%)	12.9

*Means followed by different letters in a column differ significantly and those followed by the same letter are not significantly different at p<0.05 level of significance. NS: no significant at p<0.05, WP = water productivity and HI = harvesting index

3.9. Economic Comparison of Treatments

Data pertaining to economic comparison is presented in Table 13. The highest and lowest total cost of 63812.00 and 34056.00 ETB was incurred for plastic mulching condition and no mulching condition, respectively. Moreover, the highest and lowest total cost of 30914.20 and 15007.10 ETB was incurred for CFI and AFI method, respectively. The partial budget analysis revealed that the highest net benefit of Birr 43099.30 with highest benefit-cost ratio of about 2.18 was obtained from straw mulching condition. However, the lowest benefit-cost ratio of about 1.39 with net benefit of 25165.90 was obtained from plastic mulching condition. While, the highest benefit-cost ratio of about 4.44 was obtained from AFI method however, the lowest benefit-cost ratio of about 2.91 was obtained from CFI condition.

Based on the biological data, CFI water application method combined with plastic mulch gave the maximum maize yield and the highest water productivity value was recorded at the AFI water application method with plastic mulch. Even though, we have obtained a higher maize yield at CFI and better maize yield as well as water productivity value from plastic mulch treatments, they were not economically feasible in order to recommend this result for farmers. Therefore, application of straw mulch amid a net benefit (43099.30 birr/ha) and benefit-cost ratio of about 2.18 is found to be economically feasible under alternative furrow irrigation method which was scored the highest benefit-cost ratio of about 4.44 (Baye, 2011).

Table 9. Economic analysis of maize yield production under different treatments

	Treatments	Total Return (Birr/ha)	Total cost (Birr/ha)	Net Income (Birr/ha)	Benefit cost ratio
Irrigation type	CF	90038.00	30914.20	59123.8	2.91
	AF	66644.00	15007.10	51636.9	4.44
	FF	59223.00	15507.10	43715.9	3.82
Mulch type	plastic	88977.90	63812.00	25165.9	1.27
	straw	79533.30	36434.00	43099.3	1.98
	No mulch	68985.40	34056.00	34929.4	1.84

3.10. Correlation of Yield and other Parameters

The result reveals that grain yield production per hectare was very highly significantly (p<0.001) associated positively with all parameters recorded except water productivity (Table 14).The data reveal that statistically grain yield production had no significant (p>0.05) association with the water productivity. The correlation analysis showed that there is a strong association between grain yield with yield components with the Pearson coefficient of 0.683, 0.654, 0.693, 0.813, 0.835, 0.727 and 0.593 for plant height, cob length, leaf area index, cob weight with seed, above ground biomass, straw weight, and thousand seed weight, respectively. This reveals that the increase in these parameters might lead to enhancement of grain yield. Among these parameters, aboveground biomass had the highest positive direct effect on grain yield followed by cob weight with seed and straw yield. This study is in line with the findings of Mulugeta and Kannan (2015).

Even if statistically grain yield production had no significant (p>0.05) association with the water productivity, it was correlated negatively with most of the studied parameters except harvesting index, thousand seed weight and grain yield. The explanation for this is that the enhancement of water productivity was with a compromise with reducing the yield components due to the reduction of irrigation water amount. However, the result is in disagreement with different researches who reported different condition in correlation between grain yield and WUE. Shamsi *et al*. (2010) reported WUE positively correlated with grain yield and yield components. Blum (2009) reviewed different research works and explains plant water stress results in high WUE. However, this is not an all time circumstance and WUE may vary due to different factors like environment, crop type and variety, water stress condition and crop growth stage in which moisture stress happen. Thus, the relation between yield and water productivity range from no relationship to negative or positive relationships, depending on the crop and the environment (Blum, 2009).

Table 10. Pearson's correlation coefficients (r) of growth, growth components, yield and yield components of maize as influenced by application methods in furrow irrigation and types of mulches at Hawassa

	LAI	CL	PH	CWWS	TSW	GYPH	BMPH	SYPH	HI	WUE
LAI	1									
CL	0.603***	1								
PH	0.828***	0.653***	1							
CWWS	0.600**	0.712ns	0.613**	1						
TSW	0.482***	0.598**	0.526**	0.579*	1					
GYPH	0.693***	0.654***	0.683***	0.810***	0.593**	1				
BMPH	0.733***	0.753***	0.803***	0.790***	0.612**	0.835***	1			
SYPH	0.844***	0.730***	0.781***	0.650***	0.569**	0.727***	0.983***	1		
HI	0.321ns	0.278ns	0.228ns	0.564*	0.289ns	0.714***	0.219ns	0.049ns	1	
WUE	-0.216ns	-0.046ns	-0.341ns	-0.110ns	0.090ns	0.044ns	-0.031 ns	-0.073ns	0.122ns	1

*, ** and *** = significantly correlated at 5 and 1% level, respectively, PH= plant height, BMPH = above ground biomass, LAI = leaf area index, GYPH = grain yield, TSW = thousand seed weight, CL = cob length, WP = water productivity, HI = harvest index, SYPH= straw yield, CWWS = cob weight with seed

4. CONCLUSION AND RECOMMENDATIONS

4.1. Conclusion.

The current study revealed that application of irrigation water with conventional furrow method improved maize yield than alternate and fixed furrow methods. Moreover, application of plastic mulch leads to significantly higher yield and yield components of maize than straw mulch and no mulching condition. Besides maize productivity, water use efficiency was enhanced due to the application of plastic mulch when combined with alternate furrow method as it leads to higher grain yield with the lower irrigation water application through conserving soil moisture. The effect of mulching on water use efficiency was significantly pronounced under alternate and fixed furrow methods.

Based on the objective, among the nine treatments used in this experiment, water application methods in AFI at straw mulch condition was the best treatment to be selected economically. However, the conventional furrow irrigation with plastic mulch condition demonstrated the highest biomass, grain yield and yield parameters measured except in water use efficiency. Despite this fact alternate furrow irrigation method with both mulch types shows better WUE was observed in 50% less application of water as compared to the conventional furrow irrigation method.

Therefore, water saved could be used to cultivate additional land in areas where there is water scarcity and it could increase the cultivated land especially in regions having a scarcity of natural resources. In general plots received AFI treatments were able to deliver comparable yield and yield parameters such as leaf area index, cob length, seed weight, above ground biomass per hectare, plant height, grain yield per hectare and water use efficiency.

The partial budget analysis revealed that the highest net benefit of Birr 43099.30 with a highest benefit-cost ratio of about 2.18 was obtained from straw mulching condition. However, the lowest benefit-cost ratio of about 1.39 with a net benefit of 25165.90 was obtained from plastic mulching condition. While, the highest benefit-cost ratio of about 4.44 was obtained from AFI method however, the lowest benefit-cost ratio of about 2.91 was obtained from CFI condition. Therefore, application of straw mulch amid a net benefit (43099.30 birr/ha) and benefit-cost ratio of about 2.18 is found to be economically feasible under alternative furrow irrigation method which was scored the highest benefit-cost ratio of about 4.44.

4.2. Recommendations

- Under no water scarce condition irrigation water could be used in conventional irrigation method to improve maize biomass and grain yield without application of mulch. However, under limiting irrigation water condition, alternate furrow could be practiced with straw mulch is found to be economically feasible for improving maize and water productivity in the study area and similar agro-ecology.
- Researches done before conclude that AFI and the application of mulch saves water, Therefore it is about time that AFI and mulches be tested under field condition practically for high feeder crops like sugarcane, cotton, etc. all the evidences show that there will be an imperative saving in terms of water productivity and comparable yield improvement.

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