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Integrated effect of Furrow Irrigation Methods and Types of Mulches on Yield and Water Productivity of Maize (*Zea mays* L.) in Hawassa, Ethiopia

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ውኃ በጥንቃቄ ካልተያዘ እና ካልተቀናበረ የግብርና ምርት እና ምርታማነትን በእጅጉ ሊገድብ ከሚችሉ ግብዓቶች ውስጥ አንዱና ዋነኛው ይሆናል፡፡ በደቡብ ኢትዮጵያ በሀዋሳ ከተማ የጉዝጓዝ ዓይነቶች እና የውኃ አተገባበር ዘዴ በውኃ ምርታማነት፣ በበቆሎ ሰብል ዕድገት እና ምርታማነት ላይ ያላቸውን ውጤት ለማጥናት እ.ኤ.አ. በ 2018 በበጋ ወቅት የመስክ ሙከራ ተካሂዷል፡፡ ሦስት ዓይነት የቦይ (ፈሮዉ) የመስኖ ዘዴዎች (ተለዋጭ፣ ቋሚ እና መደበኛ) እና ሶስት የጉዝጓዝ ዓይነቶችን (ምንም ጉዝጓዝ የሌለው፣ ፕላስቲክ እና ገለባ) በነጠላ እና በቅንጅት ትክክለኛዉን የመስክ ዲዛይን በመጠቀም ማለትም የመስኖ ዘዴዎችን እንደ ዋና መደብ እና የጉዝጓዝ ዓይነቶችን እንደ ንዑስ መደብ በሶስት ጊዜ ድግግሞሽ የበቆሎ ሰብል ተዘርቷል፡፡ የተገኙት ውጤቶች እንደሚያመለክቱት የተለያዩ የቦይ የመስኖ ዘዴዎች በበቆሎ ሰብል ቁመት፣ በዘር ተሸካሚ (ኮብ) ርዝመት እና ክብደት፣ በላይኛው ግዝፈ ሕይወት፣ የሰብል ምርታማነት እና የውኃ አጠቃቀም ውጤታማነት ላይ ከፍተኛ ተፅእኖ እንዳላቸው ያሳያል፡፡ የቦይ መስኖ ዘዴ ዓይነቶች በከፍተኛ ደረጃ የሰብል ምርታማነት እና የዘር ክብደት ላይ ከፍተኛ ተፅእኖ እንዳላቸው ያሳያል፡፡ በተጨማሪም የተለያዩ የጉዝጓዝ ዓይነቶችየውሃ ምርታማነትን በመጨመር የበቆሎ ዕድገት ፣ በበቆሎ ምርት እና ምርታማነት ክፍሎች ላይ ከፍተኛ ጭማሪን አስገኝተዋል፡፡ ከሌሎቹ የመስኖ ዘዴዎች አንጻር የበቆሎ ምርታማነት በከፍተኛ ደረጃ በመደበኛ የመስኖ ዘዴ ላይ ተመዝግቧል፤ ከፍተኛው የበቆሎ ምርታማነት (9003.8 ኪ.ግ. በሄክታር) የተገኘው ከመደበኛዉ የመስኖ ውሃ አጠቃቀም ዘዴ ነው ፡፡ ሆኖም ግን ከፍተኛ የውሃ ምርታማነት (2.43 ኪ.ግ በሜትር ኩብ) የተገኘዉ ከተለዋጭ የቦይ መስኖ ዘዴ ነዉ፡፡ በተጨማሪም የውሃ አጠቃቀምን ውጤታማነት በመጨመር ከፍተኛ ምርትና የምርት ክፍሎች የተመዘገቡት ከፕላስቲክ ጉዝጓዝ ነዉ፡፡ ከፍተኛው የበቆሎ ምርታማነት መጠን (8088.9 ኪ.ግ. በሄክታር) እና የውሃ ምርታማነት (2.34 ኪ.ግ በሜትር ኩብ) ፕላስቲክ ጉዝጓዝ ላይ የተመዘገበ ሲሆን ፣ከፊል የበጀት ትንተና እንደሚያሳየው ግን በሀዋሳ አካባቢ የፕላስቲክ ጉዝጓዝ ከተነጠፈበት ማሳ ይልቅ የገለባ ጉዝጓዝ የተደረገበት ማሳ የበቆሎ ምርታማነት ለገበሬዎች የበለጠ ኢኮኖሚያዊ ሊሆን እንደሚችል ተረጋግጧል፡፡ ስለዚህ ይህ ጥናት እንደሚያመለክተው የበቆሎ ምርት ለመጨመር የውሃ ችግር በሌለበት ሁኔታ መደበኛ የቦይ መስኖ ዘዴ መጠቀም ተመራጭ ሲሆን የውሃ እጥረት ባለበት ሁኔታ ግን የውሃ ትነትን ለመቀነስ፣ የበቆሎና የውሃ ምርታመነትን ለመጨመር ተለዋዋጭ ቦይ የመስኖ ዘዴ ከገለባ ጉዝጓዝ ጋር በሃዋሳ እና ተመሳሳይ የግብርና ሰነምህዳርና የአፈር አይነት ባለባቸው ቦታዎች መጠቀም ይመከራል፡፡

Abstract

Efficiency of water can be improved by making the right decision regarding to irrigation scheduling, irrigation application techniques and conservation mechanisms. A field experiment was conducted in a dry season of 2018 to investigate the effects of mulch types and water application methods in furrow irrigation system on water productivity, and yield and yield components of maize (Zea mays L.*) at Hawassa, Southern Ethiopia. Factorial combinations of three types of furrow irrigation methods (alternate, fixed and conventional) and three mulch types (no mulch, plastic, and straw mulch) were laid out in split-plot design with furrow irrigation methods as main plot and mulching as sub-plot and replicated three times. Results indicated that different types of furrow irrigation methods had a very highly significant effect on plant height, cob length and weight, aboveground biomass, grain yield, and water use efficiency of maize. Types of furrow irrigation method highly significantly affected thousand grain weight and harvesting index. Moreover, maize growth, yield and yield components including water productivity were highly significantly influenced by different mulch types. However, irrigation method by mulching type interaction was not significant for any of the studied parameters). Significantly higher yield and yield component of maize were recorded from conventional furrow irrigation method than alternate and fixed furrow irrigation method. The highest maize grain yield of 9003.8 kg ha^{-1} was achieved from conventional furrow irrigation water management method. However, higher water productivity (2.43 kg/m^3) was obtained from alternate furrow irrigation method. Moreover, higher yield and yield components including water use efficiency were obtained from plastic mulch than no mulch and straw mulch. The maximum grain yield of 8088.9 kg ha^{-1} and water productivity (2.34 kg/m^3) were obtained from plastic mulch, but the partial budget analysis revealed that straw mulch was more economically feasible for farmers than plastic mulch for maize production 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, alternate furrow irrigation method with straw mulch application could be used to minimize evaporation loss and maximize water productivity and yield of maize at Hawassa and similar agro-ecology and soil type.*

Keywords: Furrow irrigation, maize, mulching, water productivity, yield and yield components

Introduction

Natural resource degradation is a serious problem in Ethiopia threatening agricultural development and rural livelihoods (Birhanu, 2014). The rapid population growth worldwide in general and in developing countries in particular 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 resources, 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 land (Hofwegen van and Svendesen, 2000).

Agriculture is the main water-consuming sector worldwide (Biswas, 1997),which accounts 70% 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 in different parts 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 production and the competition between different sectors. The main issue for both irrigated as well as rain-fed 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 main soil and water management practices to improve water use efficiency and crop yield. Mulching material may be either organic or inorganic. Plastic is most frequently used inorganic mulch which is effective to cultivate earlier produce by controlling weeds and warming the soil (Katherine *et al.*, 2006). Organic mulches such as straw, hay, grass or plant leaf can provide multiple benefits for improving soil, water, and crop productivity (Agegnehu *et al*., 2012). 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 (Agegnehu *et al*., 2012; Kuepper *et al*., 2012).

Irrigation is widely practiced in different parts 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 practices, such as 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, including supplementary irrigation, evaporation minimization techniques such as mulching and greenhouse farming, different furrow irrigation management methods and other suitable technologies. For selected crops, application of water using such water saving technologies could improve the water productivity without significantly affecting 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 conserved 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 be saved by using alternate, furrow irrigation system and applying mulches in maize crop in Hawassa.

Although a few studies were undertaken on the effect of mulching and furrow methods on crop yield and water productivity in different parts of Ethiopia (Meskelu *et al*., 2018; Mlugeta and Kannan, 2015), the combined effects of different water application methods and mulch types on maize yield and water productivity is inadequate for the study area. Therefore, the objectives of this study were to: 1) investigate the main and interaction effects of different mulch types and furrow irrigation water application methods on water productivity, yield and yield components of maize; and 2) determine the economic feasibility of suitable mulch types and water application methods for maize production at Hawassa.

Materials and Methods

Description of the study site

The study was conducted in a dry season of 2018 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. Hawassa the capital city of SNNPR state, which is located about 275 km south of Addis Ababa (Fig. 1). Based on the long-term (1985–2015) climatic record of Southern zone National Meteorological Agency, the average annual rainfall for the last 30 years is 960 mm. The area has two rainy seasons, i.e. short rains occur from March to May and the main rainy season from June to October. However the main rainy season can extend from April to September interrupted by some dry spells in June and sometimes in May. The dry season extends from November to February (Fitsum, 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).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 a pH of 7.84. The most commonly cultivated crops in its surrounding areas are Maize (*Zea mays* L.) and Wheat (*Triticum aestivum* L.).

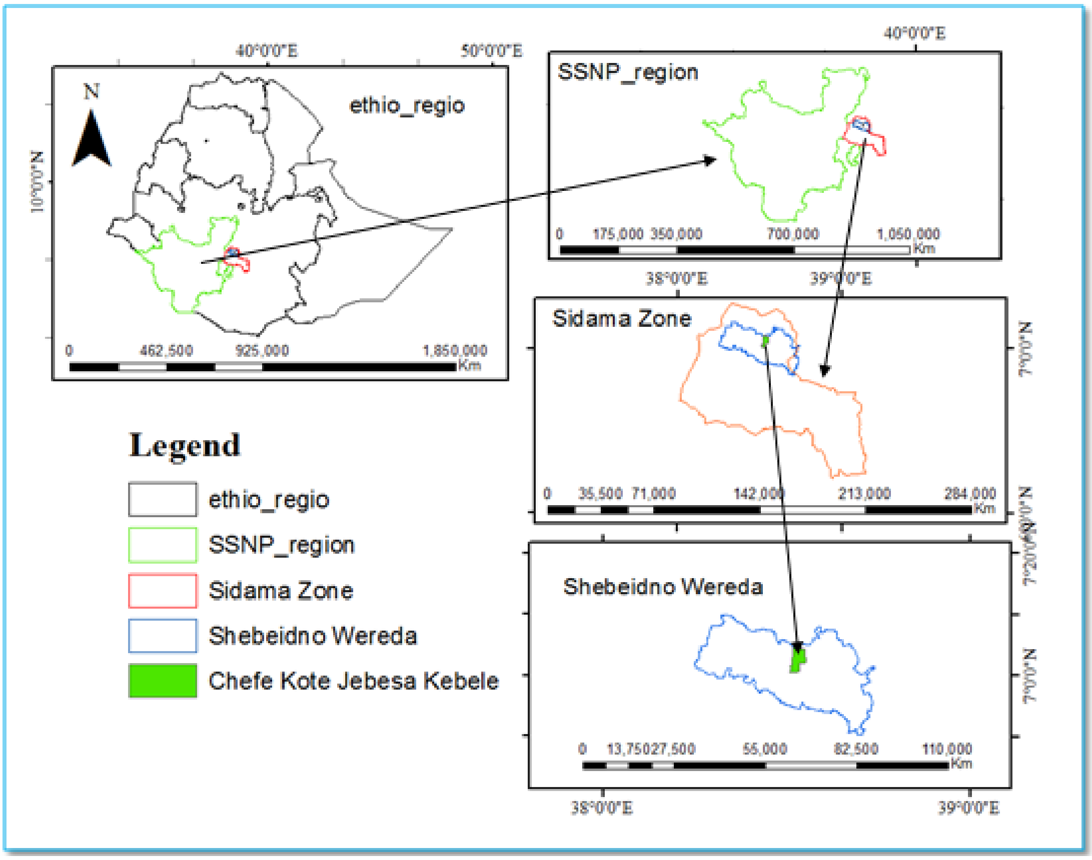

Fig. 1. Location map of the study area

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

Month	T_{max} (°C)	T_{min} (°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

Experimental design and procedure

The treatments included factorial combinations of three types of furrow irrigation methods (alternate, fixed and conventional) and three mulch types (no mulch, plastic, and straw mulch), which were laid out in split-plot design with furrow irrigation methods as main plot and mulching as sub-plot with three replications.. The mulching rate of 5 t ha^{-1} 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.

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

The amount of irrigation water applied was calculated using CROPWAT 8.0 software by using the necessary data, including crop, soil and long term climatic data. Par shall flume size of 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 given treatment was calculated for different head available under field condition. Water was 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.

Determination of soil physical properties

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

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

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).

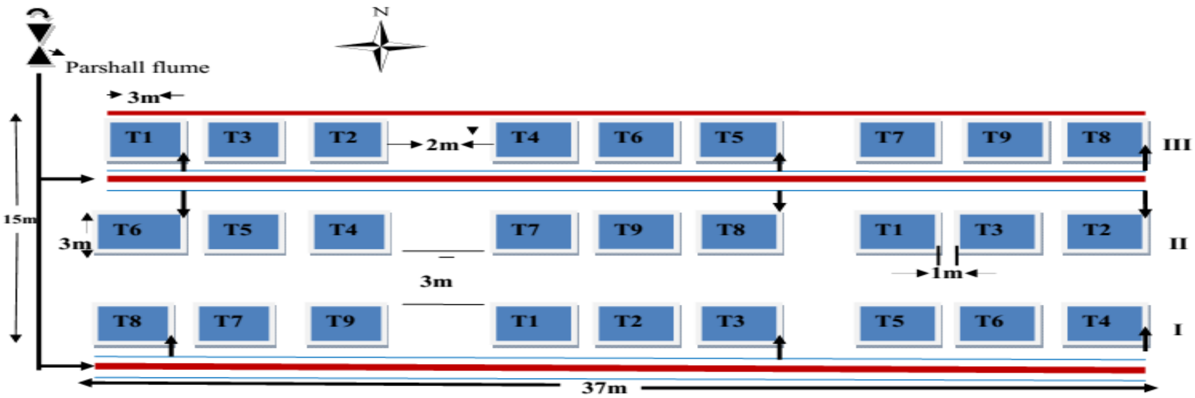

Fig. 2. Layout of the experimental plots

Soil moisture determination. The soil sample was collected using soil auger based on the root depth of the crop (0-15 cm, 15-30 cm, 30-60 cm and 60-90 cm) for monitoring the moisture content of the soil and oven dried at 105^0C 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 basis using the following equation (Jaiswal, 2003).

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

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

Field capacity and permanent wilting point. Soil samples were collected from three depths of 0-30 cm, 30-60 cm and 60-90 cm for the determination of moisture content at field capacity (FC) and permanent wilting point (PWP) 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 by using the following equation:

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

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.

Crop water and irrigation water requirement

Determination of crop water requirement. Calculation of daily ETo was computed using Crop Wat 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.

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

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).

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

Determination of net irrigation water requirement. This 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.

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

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

$$Peff = 0.8 * P - 8 \quad \text{for daily precipitation greater than } 23.3\ mm \quad (8)$$

$$Peff = 0.6 * P - 3.33 \quad \text{for daily precipitation less or equal to } 23.3mm \quad (9)$$

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.

Data collection and analysis

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.

Water Productivity (WP). WP 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).

$$\text{Water productivity}\left(\frac{kg}{m^3}\right) = \frac{\text{Grain yield}\left(\frac{kg}{ha}\right)}{\text{Seasonal net amount of water}\left(\frac{m^3}{ha}\right)} \quad (11)$$

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:

$$NI = TR - TVC \quad (12)$$

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.

Results and Discussion

Selected soil physical and chemical characteristics of the experimental plots

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

The soil pH the experimental site was 7.84, which is moderately alkaline. The EC value (0.18 ds/m) was low considering the standard rates in the literature (Landon, 1991), indicating that soil salinity was not a problem at the time for maize production. 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 ideal for crop production. The weighted average organic matter content of the soil was about 3.52%, which was classified as medium according to Staney and Yerima (1992). The average total soil nitrogen and available phosphorus concentrations were about 0.17 % and 5.51 mg kg^{-1}, respectively (Table 4).

Table 4. Soil chemical characteristics of the experimental site

Soil chemical properties	Test results
pH	7.84
Organic matter content (%)	3.52
Total nitrogen (%)	0.17
Available phosphorus (mg kg^{-1})	5.51
Electrical conductivity (ds/m)	0.18

Infiltration capacity

The data collected from the field using double ring infiltrometer were used to generate the infiltration rate curve as shown in Fig. 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 to 30 mm/hr.) (FAO, 1979).

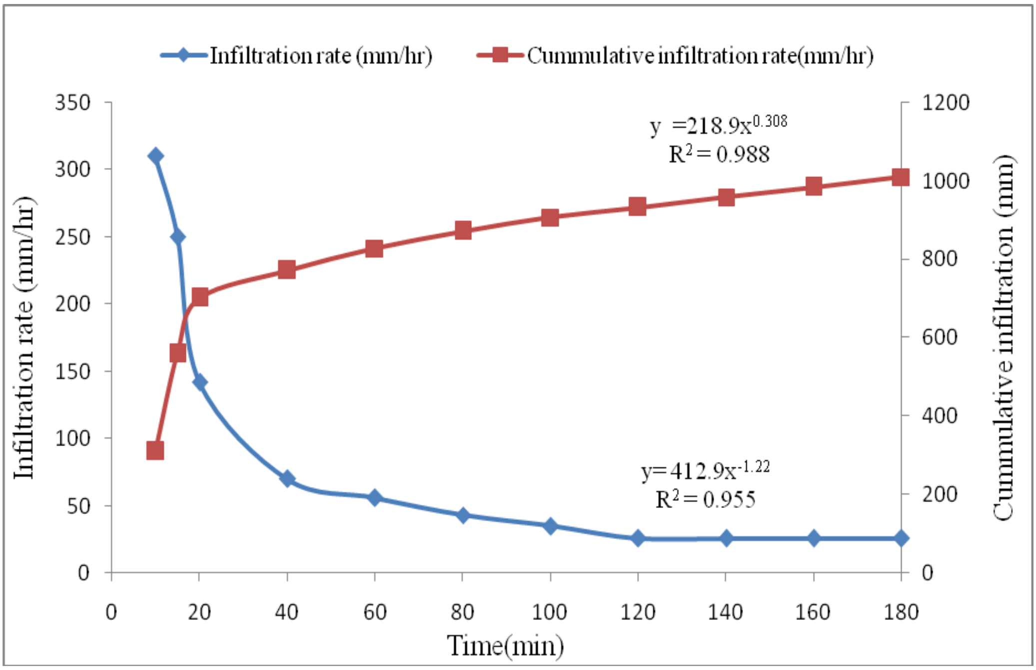

Fig. 3. Infiltration capacity of the experimental soil

Irrigation water requirement and amount

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 soil available water was 143 mm (Table 3). The net irrigation requirement was calculated using the CROPWAT 8 Computer program as presented in Table 5.

Table 5. Net and gross irrigation water applied to the experimental plot

Date	Net irrigation water applied(mm)			Gross irrigation water applied (mm)		
	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
Total	**488.6**	**244.30**	**244.30**	**814.3**	**407.17**	**407.17**

Note: CFI=conventional furrow irrigation, AFI=alternative furrow irrigation,FFI= fixed furrow irrigation

Effect of water application methods and types of mulches on growth and yield of maize

Plant height

The analysis of variance revealed that plant height was highly significantly (p<0.001) influenced due to the use of different irrigation water management methods and types of mulch (Table 7). The tallest plant height of 245.43 cm was recorded from conventional furrow method, which was statistically superior to both fixed and alternate furrow methods. In contrast, the shortest plant height of 177.19 cm was obtained from the fixed furrow irrigation method, but not statistically not significant with that of alternate furrow irrigation water management method (Table 7). .

The study also revealed that the use of plastic mulch resulted in the tallest plant height of 194.2 cm, but not statistically significantly different from straw mulch. On the other hand, the tallest plant height of 179.5 cm was recorded from the control treatment without mulch, and it was statistically inferior to application of both straw and plastic mulch. The highest plant height recorded from the conventional furrow irrigation method was higher by 38.5% than the fixed furrow irrigation method. Plastic mulching also increased plant height by 8.1% compared to the control with no mulching. This might be due to sufficient soil moisture content in the root zone due to higher irrigation depth application in conventional furrow irrigation method than alternate and fixed furrow methods, where the later possibly led to moisture stress. In contrast, plastic mulching may have brought about conservation of the available soil moisture by reducing evaporation which could improve the growth of maize. Recent studies reported that conventional furrowirrigation method resulted in higher plant height and yield components than alternate and fixed furrow methods (Meskelu *et al*., 2018; Mulugeta and Kannan, 2015; Zelalem, 2017). Dehkordi and Farhadi (2016) and Meskelu *et al*. (2018)

also reported that different mulching types significantly improved growth and plant height of maize.

Cob length and weight

The analysis of variance revealed that different types of irrigation water management methods and mulch types highly significantly ($p<0.001$) influenced maize cob length (Table 7). The longest cob length (20.44 cm) was recorded from the conventional furrow irrigation water application method, but not statistically significantly different from alternate and fixed furrow irrigation methods. In contrast, the shortest cob length (18.16 cm) was obtained from the fixed furrow irrigation method, but statistically similar with that of alternate furrow irrigation method.

The results also revealed that cob length was highly significantly affected due to the application of different mulch types. The longest cob length of 20.27 cm was recorded from plastic mulching, but statistically similar with that of straw mulch. Conversely, the shortest cob length of 17.74 cm was obtained from the control treatment without mulching, which was statistically significantly lower than both plastic and straw mulch types. This might be due to the highest soil moisture content in the root zone because of high irrigation water depth in conventional furrow method, which may have led to favorable growth condition. This is in agreement with other studies (Meskelu *et al*., 2018; Mulugeta and Kannan, 2015; Zelalem, 2017) who reported that conventional furrow irrigation method resulted in the highest yield components such as plant height and cob length followed by an alternate and fixed furrow. A similar finding was reported by Singh et al. (2016) who reported application of rice straw mulch at 6 t ha^{-1} enhanced plant height and yield attributes.

The analysis of variance revealed that highly significant ($p<0.001$) difference was observed on maize cob weight with grain due to the use of different types of irrigation water management methods and mulching during the study season. Statistically higher cob weight of 287 g was obtained from conventional furrow method was than both alternate and fixed furrow methods. The lowest cob weight of 193 g was recorded from fixed furrow method, which was statistically inferior to both conventional and alternative furrow irrigation water management methods. The study also revealed that highest cob weight with grain (262.28 g) was obtained from plastic mulch, which was statistically significantly superior to both straw mulch and the control treatment without mulch. In contrast, the lowest cob weight with grain (213 g) was recorded from the control, which was statistically significantly inferior to both plastic and straw mulch types. This finding is in line with previous 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)
	CF	205.43^a	20.44^a	287.04^a
Irrigation type	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
	plastic	194.16^a	20.27^a	262.28^a
Mulch type	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

Note: 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

Effect of furrow irrigation methods and mulch types on maize yield and yield components

Total aboveground biomass and grain yield

The analysis of variance indicated that different types of furrow irrigation water management methods showed a very highly significant ($p<0.001$) influence on maize aboveground biomass (Table 9). The highest aboveground biomass of 47.70 t ha^{-1} was obtained from conventional furrow method (100% ET_C), which was statistically significantly superior to both alternate and fixed furrow irrigation methods. Conversely, the minimum aboveground biomass of 36.68 t ha^{-1} was obtained at fixed furrow irrigation method, but statistically similar with that of alternate furrow irrigation method. Application of conventional furrow irrigation method resulted in maize total biomass increment of 30.2 %improvement compared to the fixed furrow irrigation method.

The analysis of variance also revealed that different types of mulch had a highly significant ($p<0.001$) influence on maize aboveground biomass (Table 9). Plastic mulching resulted in the maximum aboveground biomass of 45.67 t ha^{-1}, but statistically similar with that of use of straw mulch. While the minimum aboveground biomass of 36.40 t ha^{-1} was obtained from the control, which was statistically inferior to both treatments. The use of plastic mulching increased the total maize aboveground biomass by 25% over the control without mulching. This might be due to high soil moisture content in the root zone owing to high irrigation water depth in conventional furrow irrigation method, which possibly led to 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) also indicated that moisture stress in plants reduces photosynthesis capacity by reducing chlorophyll content and damage of the reaction center of the photosystem. A similar finding was also reported by Mulugeta and Kannan (2015) in that higher total aboveground biomass and grain yield of maize were obtained from conventional furrow irrigation method with irrigation water application of 100% crop water requirement than the alternate and fixed furrow irrigation methods.

Results showed that grain yield of maize differed highly significantly (p < 0.001) among different types of furrow irrigation water management methods, where the highest grain yield of 9004 kg ha^{-1} was recorded from conventional furrow irrigation water management method (Table 9). In contrast, the minimum grain yield of 5922 was obtained from fixed furrow irrigation method, but statistically similar with that of alternate furrow irrigation method (Table 9). The conventional furrow irrigation method resulted in a grain yield improvement of 52% compared to the fixed furrow irrigation method, indicating that water application in the fixed furrow irrigation method caused the greatest yield reduction of.

The analysis of variance also revealed that different types of mulch had a highly significant (p<0.01) influence on maize grain yield. The highest grain yield of 8089 $kgha^{-1}$ was achieved from plastic mulching, but statistically at par with that of straw mulching (Table 9). Conversely, the lowest grain yield of 6271 kg ha^{-1} was obtained from the control treatment without mulching, which was significantly inferior to both plastic and straw mulch types. Application of plastic and straw mulch types improved grain yield of maize by 29% and 15.3%, respectively over the control treatment without mulching. . The current finding is in agreement with Meskelu *et al*. (2018) who reported that maize grain yield was increased by 16.9% due to the use of black plastic mulch relative to the traditional practice without mulch. Yaseen et al. (2014) also revealed that maximum increase in total biomass (29.56%) and grain yield (35.5%) of maize were recorded from the application of mulch and higher irrigation depth treatments. Although irrigation method by mulching types interaction was not statistically significant, the maximum and minimum mean maize grain yields of 10119 kg ha^{-1} and 4696 kg ha^{-1} were achieved from conventional furrow irrigation method with plastic mulch and fixed furrow irrigation method with no mulch condition, respectively.

Thousand grain weight

The analysis of variance revealed that 1000-grain weight was significantly (p<0.01 and p<0.05) influenced due to the application of different types of furrow irrigation water management methods and different mulching types (Table 9). The highest 1000-grain weight of 442 g was recorded from conventional furrow irrigation method, which was statistically at par with that of alternate furrow irrigation method. On the other hand, the minimum 1000-grain weight of 365.3 g was obtained from fixed furrow irrigation method which was statistically significantly inferior to both conventional and alternate furrow irrigation methods. Similarly, the maximum 1000-grain weight (432.1 g) recorded from plastic mulching was statistically superior to the control without mulch, but not statistically significant with straw mulch condition. In contrast, 1000-grain weight of 381.1g was observed under no mulching condition, which was statistically similar to that of straw mulch but inferior to that of plastic mulch condition.

The maximum 1000-grain weight recorded due to conventional furrow irrigation methods was 11.4% higher than that observed under fixed furrow irrigation method. In addition, application of plastic mulch had an improvement of 1000-grain weight by 12% over no mulch condition (Table 9). Thus, grain weight is strongly associated with the amount of applied irrigation water as well as use of mulches. This study agrees with the study of Mansouri *et al*. (2010) who reported that when the amount of applied water increased, both the thousand grain weight and yield were substantially increased. Similarly, Meskelu *et al*. (2017) reported that application of lower irrigation depth produced lighter wheat grain weight under irrigation. Awal and Khan (2000) also reported use of mulching improved maize yield and yield components.

Table 7. Effects of water application methods in furrow irrigation and types of mulches on yield and yield components of maize

Treatments		Aboveground total biomass ($t\ ha^{-1}$)	Grain yield ($kg\ ha^{-1}$)	Thousand grain weight (g)
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

Note: 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.

Effect of water application methods and types of mulches on water productivity

Water productivity

The different types of furrow irrigation water management methods showed a very highly significant (p<0.001) influence on water productivity of maize (Table 11). Results indicated that the water productivity of maize was higher under alternate furrow irrigation method than conventional and fixed furrow irrigation methods. The maximum water productivity of 2.43 kg/m^3 observed at alternate furrow method was statistically superior to both conventional and fixed furrow irrigation methods. The minimum water productivity of 1.64 kg/m^3 was observed at conventional furrow irrigation method, which was statistically inferior to both alternate and fixed furrow methods during the growing season (Table 11). The irrigation water application method of alternative furrow (50%ETc) gave proportionally higher water productivity than conventional furrow irrigation method (100% ETc). The lowest water productivity recorded at 100% ET_C might be attributed to application of higher irrigation water depth, much of which was lost through soil evaporation and deep percolation. The higher amount of irrigation water application could be associated with lower water use efficiency, while the lower amount of irrigation water amount may be associated with higher water use efficiency.

Analysis of variance indicated that different types of mulch highly significantly ($p<0.01$) influenced water productivity of maize. Higher water productivity was observed under plastic mulching condition than under the control and straw mulching condition. The maximum water productivity of 2.34 kg/m^3 was obtained from plastic mulching, which was statistically significantly superior to the control without mulch, but not statistically significantly different from straw mulch treatment. The minimum water productivity of 1.80 kg/m^3 was observed under no mulch condition, which was statistically inferior to both straw and plastic mulching at different irrigation water management methods. The highest obtained at alternate furrow irrigation method resulted in water productivity increase of 48% compared to the conventional furrow irrigation method. However, plastic mulching increased water productivity by 30% compared to the control without mulch.

Although significant ($p<0.05$) interaction effect was not observed between irrigation type and mulch type on improving water use efficiency (WUE), the maximum water use efficiency of 2.67 kg/m^3 was observed at plastic mulching combined with alternate furrow irrigation method. On the other hand, the minimum water use efficiency of 1.48 kg/m^3 was obtained from conventional furrow irrigation method under no mulch condition. Different studies revealed that water application methods in furrow irrigation and types of mulches had a significant effect on water productivity of irrigated maize (Elias *et al*., 2018). The study of Kang *et al*. (2000) indicated that alternate furrow irrigation method showed better performance for increasing WUE (2.67 – 5.75 kg/m^3) relative to fixed furrow irrigation, which resulted in significant reduction in maize grain yield. Thind *et al*. (2010) reported that alternate furrow irrigation increased water use efficiency in the wheat-cotton rotation in Punjab, India. Moreover, application of alternate furrow irrigation method significantly increased water productivity compared to conventional furrow irrigation in sugarcane fields in southern part of Iran (Sheynidashtgol *et al*., 2009). Kang *et al*. (2000) also evaluated the alternate furrow irrigation, fixed furrow irrigation and conventional furrow irrigation methods with different irrigation amounts for maize production. This study showed that different mulching types had a significant role in maximizing water productivity. Xu *et al*. (2015) reported that water use efficiency of maize under plastic mulching (3.27 kg/m^3) was increased by 16% compared to the control treatment without mulching, despite similar overall evapotranspiration between the two treatments. Montazar and Kosari (2007) also reported that mulching could enhance water use efficiency of different crops including maize by conserving moisture in the soil for proper utilization by the plant.

Table 8. Effect of water application methods using different furrow irrigation methods and types of mulches on water productivity

Treatments		Water productivity (kg/m^3)
Irrigation type	CFI	2.16^b
	AFI	2.43^a
	FFI	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

Note: 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: not significant at p<0.05; CFI = Conventional furrow irrigation; AFI = Alternate furrow irrigation; FFI = Fixed furrow irrigation.

Correlation of yield and yield components, and water productivity

The results revealed that maize grain yield was very highly significantly (p<0.001) associated positively with all parameters recorded except water productivity (Table 12). The Pearson correlation analysis showed that grain yield was strongly associated with plant height, cob length, leaf area index, cob weight with grain, above ground biomass, straw weight, and thousand grain weight (r = 0.68, 0.65, 0.69, 0.81, 0.84, 0.73 and 0.59), respectively. This showed that the increase in the Pearson coefficients of the yield components may have led to enhancement of grain yield, of which cob weight and total aboveground biomass were strongly significantly (r = 0.81*** and 0.84***, respectively) correlated with maize grain yield (Table 12). This study is in line with the findings of Mulugeta and Kannan (2015).

Although grain yield was not significantly associated with water productivity, it was correlated negatively with most of the studied parameters except harvest index, thousand grain weight and grain yield (Table 12). The explanation for this is that the enhancement of water productivity was compromised with the decrease in the yield components due to the reduction of irrigation water amount. However, the result contradicted with the studies of 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) also reviewed different research works and explained plant water stress results in high WUE. However, this has not been 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 happens. Thus, the relation between yield and water productivity may range from the absence of relationship to negative or positive relationships, depending on the crop and the environment (Blum, 2009).

Table 2. Pearson's correlation coefficients (r) of growth, yield and yield components, and water productivity of maize as influenced by application methods of furrow irrigation and types of mulches at Hawassa

	CL	PH	CWWG	TSW	GY	TBM	SY	HI	WUE
CL	1								
PH	0.653***	1							
CWWS	0.712ns	0.613**	1						
TSW	0.598**	0.526**	0.579*	1					
GYPH	0.654***	0.683***	0.810***	0.593**	1				
BMPH	0.753***	0.803***	0.790***	0.612**	0.835***	1			
SYPH	0.730***	0.781***	0.650***	0.569**	0.727***	0.983***	1		
HI	0.278ns	0.228ns	0.564*	0.289ns	0.714***	0.219ns	0.049ns	1	
WUE	-0.046ns	-0.341ns	-0.110ns	0.090ns	0.044ns	-0.031 ns	-0.073ns	0.122ns	1

*, ** and *** = significantly correlated at 5, 1% and 0.1% level of significance, respectively, PH = plant height, BM = aboveground total biomass, GY = grain yield, TGW = thousand grain weight, CL = cob length, WP = water productivity, HI = harvest index, SY = straw yield, CWWG = cob weight with grain

Economic comparison of the treatments

Data pertaining to economic comparison is presented in Table 13. The highest and lowest total costs of ETB 63812.00 and ETB 34056.00 were incurred for plastic mulching condition and no mulching condition, respectively. Moreover, the highest and lowest total costs of 30914.20 ETB and 15007.10 ETB were incurred for conventional furrow irrigation and alternate furrow irrigation method, respectively.

The partial budget analysis revealed that the highest net benefit of ETB 43099.30 was obtained from straw mulching condition, with the highest benefit-cost ratio of about 2.18. However, the lowest benefit-cost ratio of about 1.39 with net benefit of ETB 25165.90 was obtained from plastic mulching condition. The highest benefit-cost ratio of about 4.44 was obtained from alternate furrow irrigation method, but the lowest benefit-cost ratio of about 2.91 was obtained from conventional furrow irrigation method.

Based on the biological data, conventional furrow irrigation water application method combined with plastic mulch gave the maximum maize grain yield, but the highest water productivity value was recorded from the alternate furrow irrigation water application method with plastic mulch. While the highest maize grain yield was obtained from the conventional furrow irrigation method and better yield as well as water productivity from plastic mulch treatments, they were not economically feasible to recommend for farmers. Therefore, application of straw mulch amid a net benefit (43099.30 Birr ha^{-1}) and benefit-cost ratio of about 2.18 and alternative furrow irrigation method which scored the highest benefit-cost ratio of about 4.44 was found to be economically feasible treatments (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

Conclusion and Recommendations

The current study revealed that application of irrigation water with conventional furrow method resulted in higher maize yield than alternate and fixed furrow methods. Application of plastic mulch recorded significantly higher yield and yield components of maize than the control and straw mulch treatments. Application of plastic mulch combined with alternate furrow irrigation method enhanced maize productivity and water use efficiency because of 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. Thus, based on the objectives of this experiment, application of alternate furrow irrigation method and straw mulch was found to be economically the best treatments. However, the conventional furrow irrigation with plastic mulch recorded the highest total biomass, yield and yield components except water use efficiency. Despite this fact alternate furrow irrigation method with both mulch types showed better WUE with 50% less application of water compared to the conventional furrow irrigation method. Therefore, the water saved could be used to cultivate additional land in areas where there is water scarcity and it could increase the cultivated land area. In general, plots received water using alternate furrow irrigation method were able to deliver comparable yield and yield components, such as grain yield, aboveground biomass, plant height cob length, thousand grain weight, and water use efficiency.

The partial budget analysis revealed that the highest net benefit of ETB43099.30 with a highest benefit-cost ratio of about 2.18 was obtained from straw mulching. However, the lowest benefit-cost ratio of about 1.39 with a net benefit of ETB 25165.90 was obtained from plastic mulching. The highest benefit-cost ratio of about 4.44 was obtained from alternate furrow irrigation method but, the lowest benefit-cost ratio of about 2.91 was obtained from conventional furrow irrigation method. Therefore, application of straw mulch amid a net benefit of (43099.30 Birr ha^{-1}) and benefit-cost ratio of about 2.18 and alternative furrow irrigation method which resulted in the highest benefit-cost ratio of about 4.44 was found to be economically feasible treatments.

Never the less, under no water scarce condition irrigation water could be applied using conventional irrigation method to improve maize grain yield without application of mulch. On the other hand, under limiting irrigation water condition, alternate furrow irrigation method could be practiced with straw mulch, which was found to be economically feasible for improving maize and water productivity in the study area and similar agro-ecology. Since previous studies concluded that application of alternate furrow irrigation method plus mulch saves water, further study could be undertaken under field condition for high feeder crops such as sugarcane and cotton.

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