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Integrated Effect of Mulching and Furrow Methods on Maize Yield and Water Productivity at Koka, Ethiopia

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Abstract

The study was conducted at Wondo Genet Agricultural Research Center, Koka research station, Ethiopia, 8°26' N latitude, 39°02' E longitude and 1602 m.a.s.l. based on the objective to select most effective water saving techniques and improve water productivity of irrigated maize (*Zea mays* L.). Three types of furrow irrigation methods (alternate, fixed and conventional furrow irrigation methods) and two mulch types and no mulch with three replications were used as two factors to evaluate the yield and yield component including water use efficiency of maize in split-plot design. Different types of irrigation method highly significantly (p<0.01) affected all the studied parameters of yield and yield components of maize at Koka both season except number of grains per cob. Moreover, maize growth, yield and yield components 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 (irrigation type 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. However, higher water use efficiency 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 for maize at koka. Therefore, 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 resource condition, irrigation of maize could be done with alternate furrow irrigation method with plastic mulch application to minimize evaporation loss and maximize water productivity of maize at Koka and similar agro-ecology and soil type.

Keywords: Alternate furrow; Conventional furrow; Fixed furrow; Plastic mulch; Straw mulch; Water productivity

Introduction

Global population growth especially in developing countries forces to increase food production. This needs different strategies like an intensification of modern agricultural crop production and increasing farm area. However, this could not be only depend on rain-fed agriculture as the climate change scenario and limited area to produce a crop in only rainy season. The challenge of crop production in rain-fed is aggravated by temporal and special variation of rainfall and further accelerated by climate changes [1].

Irrigated agriculture is currently supplying more than 40% of food and agricultural commodities within only 17% of the cropped land [2]. However, this is not without a compromise in the devastating the water resource as irrigated agriculture consumes more than 70% of water withdrawal from all sources and it is the most inefficient sector [3]. On the other hand, crop growth and yield majorly affected by environmental factors like drought which leads to a significant reduction in agricultural outputs [4].

The target crop maize is the one of the major crop in Ethiopia with is the top crop by the number of farming community engaged and next to *teff* it is the highest in area coverage in the country [5]. The study area is at central rift valley of Ethiopia where crop production in dry season is unexpected without irrigation. Moreover, it is characterized by having highly variable initial and conditional probability of threshold limit of 30 mm per decade rainfall in the main rainy season [6]. To improve crop production to feed the ever-increasing population under limiting water resource condition, strategies that conserve moisture in the soil and efficient irrigation techniques should be identified and practiced.

Different works have been done on irrigation water management for maize in different part of the world that revealed that yield and water productivity of maize enhanced through different irrigation water management methods like conventional furrow, alternate furrow and water conservation methods like application of straw and plastic mulching [7-9]. Application of irrigation water through conventional furrow method that irrigate all the neighboring furrow in two consecutive irrigation time leads to maximize yield under different crops including maize. However, productivity of irrigation water is maximized through deficit irrigation practice using different techniques like alternate furrow method by irrigating only one of the neighboring two furrows during the consecutive irrigation time. For example, Narayanan and Seid [8] reported that maximum maize yield was obtained under conventional furrow irrigation with irrigation water application of 100% crop water requirement than the alternate and fixed furrow irrigation method. The same research revealed that with comparable yield penalty, alternate furrow irrigation method maximized water use efficiency of maize. Panigrahi et al. [9] reported that alternate partial root-zone irrigation improves water use efficiency of okra plant than the conventional furrow condition under different soil moisture depletion levels. Based on their findings, Nasri et al. [10] concluded that alternate furrow irrigation as a way to save water in arid area where maize production relies heavily on repeated irrigation.

Moreover, application of mulch for conservation of soil moisture leads to higher water productivity of maize integrating with deficit

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irrigation techniques [11]. Application of mulch also leads to improve net return of crops through maximizing yield and water productivity with limited available water [12]. Mo et al. [13] reported that maize grain yield and water use efficiency was increased by 58.8 and 53.3% in black plastic mulch than non-mulch condition with alternative ridge and furrow method, respectively. Residue retention, weed control, fertilizer use, modified irrigation practices and plastic mulch could be used as strategies to improve water use efficiency in maize [14]. Therefore, this field experiment was done for two season (2014/15 and 2016/17) due to unavailability of information regarding mulching and irrigation water application method for maize in the study area based on the objective to select most effective water saving techniques and improve water productivity.

Materials and Methods

Description of experimental site

The study was conducted at Wondo Genet Agricultural Research Center, Koka research station, Ethiopia, 8°26' N latitude, 39°02' E longitude and 1602 m.a.s.l. for two dry seasons (2014/15 and 2016/2017). The soil at the experimental site was clay in textures with field capacity and permanent wilting point of 35% and 19%, respectively. The climate of the area is characterized as semi-arid with uni-modal low and erratic rainfall pattern with annual average of 831.1 mm. About 71.2% of the total rainfall of the area falls from June to September. The mean maximum temperature varies from 26.3 to 30.9C while mean minimum temperature varies from 11.0 to 15.5°C (Table 1).

Experimental design and procedure

The experiment was done in a split plot design with three irrigation water application methods (fixed, alternate and conventional furrow method) in main plot and two mulch types (straw and plastic) and control as no mulch. Each main plot factors (furrow irrigation methods) was assigned randomly within each replication and every subplot factor (mulching) was randomly assigned inside each main plot. Sub plot size of 3.0 m × 3.0 m which consists of 4 ridges spaced at 75 cm was used for mulching factor. Main plot consists of three subplots as furrow irrigation water management method. Black plastic mulch and vetiver grass (*Chrysopogon zizanioides*) straw mulch with a rate of 6 t/ha were used as mulching types in the sub plots. Seed of maize variety Melkassa-4 was sown in 30 cm intra raw with ridge spaced 75 cm after the land is prepared well. The variety was released during 1999 for moisture stress area with altitude ranging from 500-1600 m.a.s.l. The yield potential of this variety under rain-fed condition is 3-5 t/ha with

Month	Tmax (°C)	Tmin (°C)	Relative humidity (%)	Wind speed (m/s)	Sunshine hour (%)	Rainfall (mm)
January	27.4	11.3	54	4.04	75	13.5
February	28.3	12.6	52	4.08	76	26.1
March	30.0	14.4	51	4.64	74	51.5
April	30.3	15.2	54	3.80	71	58.5
May	30.9	15.1	53	3.98	68	48.5
June	30.0	15.5	57	4.91	65	72.7
July	26.7	15.0	67	4.30	54	212.7
August	26.3	15.1	68	3.15	53	202.4
September	27.8	14.9	66	2.30	57	104.3
October	28.3	12.7	56	3.50	73	21.1
November	27.4	11.3	52	4.09	83	9.9
December	26.1	11.0	54	4.19	76	9.9

Table 1: Climatic data of the study area.

day to maturity of 105. Each plots were fertilized with 46 kg/ha P and 64 kg/ha N which is a blanket recommendation for maize in the study area. Half dose of N and full dose of P were applied during sowing of maize, whereas the rest half dose of N was applied at knee height level of maize. Both straw and plastic mulching were applied a week after germination.

The amount of irrigation water applied was calculated using CROP WAT 8.0 software by using necessary input data (crop, soil and long-term climatic data). Irrigation water was applied up to field capacity by monitoring soil moisture content using gravimetric method in the conventional furrow plot. The calculated irrigation depth based on the water holding capacity of the soil in the management allowable depletion level was measured using Parshall flume before diverted to each subplots.

Data collection and analysis

Maize growth data like plant height was collected by randomly selecting five maize plants from the central two ridges and measuring from soil surface to the peak of the plant. The same crop was tagged and harvested for maize yield and yield components like aboveground biomass, cob length, cob width, and cob weight with seed, cob weight without seed, grain yield and thousand seed weight. Aboveground biomass, grain yield and thousand seed weight were measured after the sample was sun dried for three days. Water use efficiency was calculated using the following formula.

$$Water\ use\ efficiency = \frac{Grain\ yield\left(\frac{kg}{ha}\right)}{Net\ irrigation\ water\ applied\left(\frac{m^3}{ha}\right)}$$

The collected data were analyzed using statistical analysis system (SAS) version 9.0 procedure of general linear model for the variance analysis. Mean comparisons were carried out to estimate the differences between treatments using Fisher's least significant difference (LSD) at 5% probability level.

Result and Discussion

Plant height

Plant height was highly significantly ($p<0.01$) affected due to different types of irrigation water management methods (Table 2). Maximum plant height was observed for conventional furrow method, whereas the minimum 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 similar with that of alternate furrow irrigation water management method.

The pooled mean of plant height revealed that the highest plant height of 155.7 cm was recorded when irrigation water applied using conventional furrow method. While the minimum plant height of 121.9 cm was observed at fixed furrow method. However, this was statistically similar with plant height obtained at alternate furrow method (Figure 1).

The study also revealed different types of mulch also had a highly significant ($p<0.01$) effect on plant height of maize (Table 2). Maximum plant height of 140.3 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

Source of variation	df	Mean squares								
		PH	CD	CL	CWWS	CWWOS	AgBM	GY	TSW	WUE
Replication	2	34.89^{ns}	0.016^{ns}	0.01^{ns}	253.32^{ns}	29.69^{ns}	6.14^{ns}	0.39^{ns}	267.9^{ns}	0.03^{ns}
Irrigation type	2	3096.7**	0.41**	14.97**	10423.9**	817.9**	215.61**	10.91**	4834.0*	0.70**
Mulch type	2	337.8**	0.09**	6.45**	1470.2*	107.01*	35.07**	1.42*	2465.6^{ns}	0.49**
Irrigation*mulch	4	31.04^{ns}	0.02^{ns}	1.76*	498.66^{ns}	25.72^{ns}	3.60^{ns}	0.73^{ns}	429.1^{ns}	0.05*

**Significant at p<0.01; *Significant at p<0.05; ^{ns}not significant at p<0.05. df: degree of freedom; PH: Plant Height; CD: Cob Diameter; CL: Cob Length; CWWS: Cob Weight with Seed; CWWOS: Cob Weight without Seed; AgBM: Aboveground Biomass; GY: Grain Yield; TSW: Thousand Seed Weight; WUE: Water Use Efficiency

Table 2: Analysis of variance.

Figure 1: Picture taken during the field work.

height of 123.1 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 is 27.7% higher than the plant height observed at fixed furrow method. Moreover, plastic mulching improved plant height by 14.0% 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 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 increase plant height. This is in line with the findings of El-Nady and Abdallh [15] who reported conventional furrow irrigation method leads to the highest yield components and plant height followed by alternate and fixed furrow, respectively. Similar findings were also reported by Dehkordi and Farhadi [7] who reported that different mulching condition significantly affects plant height and height growth rate of maize. Singh et al. [12] also reported application of rice straw mulch (6 t/ha) enhanced plant height and yield attributes. Likewise, Yaseen et al. [16] reported that maximum increase (11.39%) in plant height was recorded on mulch and higher irrigation depth treatments.

Cob length and cob diameter

The analysis of pooled means of cob length and cob diameter showed that different types of furrow irrigation methods highly significantly (p<0.01) influenced both parameters (Table 2). Longest cob length (17.1 cm) and higher cob diameter (4.7 cm) were observed at conventional furrow irrigation water application method. The maximum cob length and cob diameter observed at conventional furrow method were statistically superior to both alternate and fixed furrow methods. Contrary to this, shorter cob length (14.7 cm) and lower cob diameter (4.3 cm) were observed when irrigation water applied using fixed furrow irrigation method. However, on both parameters the minimum value recorded was statistically similar with that of alternate furrow method. The maximum cob length and cob diameter due to conventional furrow irrigation methods were 16.3 and 9.3% higher than that observed under fixed furrow method, respectively.

Moreover, the result also revealed that cob length and cob diameter were highly significantly (p<0.01) affected due to different mulch types used. Longest cob length (16.6 cm) and higher cob diameter (4.5 cm) were observed at plastic mulching condition. The maximum cob length and cob diameter observed at plastic mulching were statistically superior to both alternate and fixed furrow methods. Contrary to this, shorter cob length (14.9 cm) and lower cob diameter (4.3 cm) were observed under no mulching condition. However, the minimum cob length observed at no mulching condition was statistically similar with that of straw mulch. On the other hand, the minimum cob diameter observed at no mulch condition was significantly inferior to both plastic and straw mulch. The maximum cob length and cob diameter due to conventional furrow irrigation methods were 11.4 and 4.7% higher than that observed under fixed furrow method, respectively.

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 leads to improve growth parameters like plant height, cob length and cob diameter. On the other hand, moisture stress due to half water depth reduction in fixed and alternate furrow irrigation method than the conventional furrow method and the partial root zone dryness constantly in fixed furrow method might lead to create unfavorable growth condition on

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maize. This leads to a reduction of root elongation and minimizes root expansion which leads to minimize nutrient and water uptake and reduce photosynthesis. Similar finding was reported by Singh et al. [12] who reported application of rice straw mulch (6 t/ha) enhanced plant height and yield attributes. El-Nady and Abdallh [15] also reported conventional furrow irrigation method leads to the highest yield components and plant height followed by alternate and fixed furrow, respectively. Different studies also revealed that different mulching level affects different growth and yield components of maize. This might be mulching improve moisture content of soil through reduction of evaporation and save water in the root zone. Similar findings were reported by Awal and Khan [17] who reported mulching improves maize growth parameters including cob diameter and length. However, the current finding is in opposing Dehkordi and Farhadi [7] who reported that different mulching condition does not affects cob length and cob diameter.

Cob weight with seed and cob weight without seed

Highly significant ($p<0.01$) difference was observed on maize cob weight with seed and cob weight without seed due to different types of irrigation water management methods during both the study season (Table 2). The higher cob weight with seed and without seed (190.2 and 48.5 g) obtained at conventional furrow method were statistically superior to both alternate and fixed furrow method during both season and pooled mean. The lower cob weights with seed and without seed (126.2 and 31.0 g) were observed at fixed furrow method. However, this was statistically similar with that of alternate furrow method. Irrigation water application in conventional furrow method leads to an improvement of cob weight with seed and without seed by 50.7 and 30.6 %, respectively.

Similarly, the pooled means of two years data revealed that different types of mulch application on maize significantly ($p<0.05$) influenced both cob weight with seed and without seed. Higher cob weight with seed and without seed of 165.1 and 41.5 g were 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 and without seed of 139.8 and 35.1 g were observed at no mulch condition which was statistically similar with that of straw mulching. Application of plastic mulch for maize improved cob weight with seed and without seed by18.1 and 18.2% than non-mulching condition, respectively.

This might be higher irrigation water depth application under conventional furrow method leads to higher moisture content of the soil which creates favorable growth condition for maize. On the other hand, moisture stress due to reduced irrigation under alternate and fixed furrow leads to affect growth parameters of maize as moisture stress affect photosynthesis. Mulching especially in the case of plastic mulch conserve the available moisture through reduction of evaporation and minimize the effect of weed competition for moisture and nutrient in the soil.

Different studies revealed that different irrigation water management method and different mulch types significantly affected maize growth parameters including cob weight. El-Nady and Abdallh [15] reported that conventional furrow irrigation method improves maize growth and yield components. Awal and Khan [16] reported mulching improve maize growth parameters and yield components. Moreover, Singh et al. [12] reported application of rice straw mulch (6 t/ha) enhanced maize green cob yield by 37% over the flat planting alone.

Seed weight

The analysis of pooled mean revealed that 1000-seed weight was significant ($p<0.05$) influenced due to different types of furrow irrigation water management methods (Table 2). On the other hand, different mulching type had no significant effect on 1000-seed weight. The highest (347.1 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 (304.3 g) 1000-seed weight was obtained at fixed furrow a condition which was statistically inferior to both conventional and alternate furrow method. This is in line with Sepaskhah and Khajehabdollahi [18] who reported the main cause of grain yield reduction at longer intervals on alternate furrow method attributes to a decrease in grain number and 1000-seed grain weight. Different former studies also revealed that application of lower irrigation depth leads to a reduction of thousand seed weight of different crops. For example, Meskelu et al. [19] reported application of lower irrigation depth leads to lighter seed weight on wheat under irrigation.

Aboveground biomass and grain yield

The analysis of pooled means and both season data reveled that different types of furrow irrigation water management methods influenced aboveground biomass and grain yield of maize highly significantly ($p<0.01$). Maximum aboveground biomass (28.28 t/ha) and grain yield (6.29 t/ha) were observed at conventional furrow irrigation water application method (Table 3). The maximum aboveground biomass and grain yield obtained at conventional furrow method were statistically superior to both alternate and fixed furrow methods. Contrary to this, minimum aboveground biomass (19.29 t/ha) and grain yield (4.20 t/ha) were obtained at fixed furrow irrigation method. The minimum aboveground biomass and grain yield obtained at fixed furrow were statistically similar with that of alternate furrow irrigation method. The highest aboveground biomass and grain yield of maize obtained at conventional furrow irrigation method lead to

Treatment		PH	CD	CL	CWWS	CWWOS	AgBM	GY	TSW	WUE
Irrigation type	CF	155.7^a	4.67^a	17.12^a	190.2^a	48.5^a	28.28^a	6.29^a	347.1^a	1.15^c
	AF	125.6^b	4.35^b	15.12^b	138.0^b	33.3^b	20.43^b	4.64^b	341.0^b	1.69^a
	FF	121.9^b	4.27^b	14.71^b	126.2^b	31.0^b	19.29^b	4.20^b	304.3^b	1.53^b
$LSD_{0.05}$		6.49	0.09	0.74	15.55	4.42	1.68	0.53	30.2	0.12
Mulch type	Straw	134.9^a	4.43^b	15.52^b	149.5^b	36.1^b	22.59^b	4.98^{a,b}	332.6	1.40^b
	Plastic	140.3^a	4.53^a	16.56^a	165.1^a	41.5^a	24.68^a	5.46^a	346.4	1.72^a
	No mulch	128.1^b	4.33^c	14.88^b	139.8^b	35.1^b	20.73^c	4.67^b	313.4	1.26^c
$LSD_{0.05}$		6.49	0.09	0.74	15.55	4.42	1.68	0.53	ns	0.12
CV (%)		4.8	2.04	4.7	10.3	11.8	7.4	10.5	9.1	8.1

^{a,b,c}Letter with similar letter in the column are not significantly different; ^{ns}not significant at $p<0.05$; CV: Coefficient of Variation; LSD: Least Significant Difference; CF: Conventional Furrow; AF: Alternate Furrow; FF: Fixed Furrow

Table 3: Means of yield and yield components (pooled mean).

an improvement of 46.6 and 49.8% than the fixed furrow method, respectively.

The analysis of pooled means and both season data also revealed that different types of mulch on maize had a highly significant ($p<0.01$) influence on aboveground biomass (Table 2). Moreover, grain yield of maize was significantly ($p<0.05$) affected by different types of mulch. Maximum aboveground biomass (22.59 t/ha) and grain yield (4.98 t/ha) were observed at plastic mulching condition. The maximum aboveground biomass obtained at plastic mulching was statistically superior to both treatments which followed by straw mulching condition. Moreover, the minimum (20.73 t/ha) aboveground biomass obtained at no mulching condition was statistically inferior to both treatments. On the other hand, the maximum grain yield obtained at plastic mulching condition was statistically similar with that of straw mulch. Moreover, the minimum (4.67 t/ha) grain yield obtained at no mulching condition was statistically similar with that of straw mulch. The highest aboveground biomass and grain yield of maize obtained at plastic mulching lead to an improvement of 19.1 and 16.9% over the conventional 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. Different studies revealed that adequate moisture in the root zone leads to improve aboveground biomass and grain yield of maize. As far as water is one of the main components of photosynthesis for plants to produce their food, supplying adequate water could leads to increase both aboveground biomass and grain yield. Makino [20] reported that 90% of plant biomass is obtained from photosynthesis product, in which water is the main component.

As the irrigation depth reduced in the case of alternate and fixed furrow, the levels of moisture stress increase. This might be the reduction in irrigation water depth leads to moisture stress which affects photosynthesis capacity of the plant and assimilation of CO_2 to produce food. Guo et al. [21] reported that moisture stress in plants reduce photosynthesis capacity by reducing chlorophyll content and damage of the reaction center of photosystem. Hence, the lower irrigation depth in case of fixed and alternate furrow method leads to create partial root zone drying and reduce the amount of water needed by the plant for photosynthesis and uptake and transportation nutrient from the soil for production of food. Similar reports was reported by Narayanan and Seid [8] 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. El-Halim [22] reported that grain yield increased under alternate furrow with frequent irrigation as compared with every furrow irrigation.

Moreover, the water conserved in case of plastic mulch leads to improve transpiration by reducing evaporation and minimize the effect of moisture stress on plants. Different studies also revealed that different mulching condition and level affects aboveground and grain yield of maize. Even though irrigation water depth is reduced due to different irrigation water management methods like alternate and fixed furrow, the applied depth could be conserved due to the reduction of evaporation from soil surface by mulching. The conserved moisture content of soil in the root zone could enhance crop transpiration and nutrient uptake and transportation in the plant body. The current finding is in line with Mo et al. [13] who reported maize grain yield was increased by 50.8% in black plastic mulch than non-mulch condition.

Mo et al. [13] reported that maize biomass was improved by 73.5% in black plastic mulch as compared with non-mulching condition. Similarly, Xu et al. [23] reported that plastic mulching improves the accumulation of dry matter, leading to a significantly greater final biomass and an improvement of grain yield of maize by 15-26% both in the dry years. Moreover, Yaseen et al. [16] revealed that maximum increase in biomass (29.56%) and grain yield (35.5%) were recorded on mulch and higher irrigation depth treatments. Panigrahi et al. [9] also revealed that application of black plastic mulching improves the yield of okra plant by 21.4 to 36.9% at different allowable soil moisture depletion level and alternate furrow irrigation method.

Water use efficiency

Water use efficiency was significantly ($p<0.01$) influenced due to different types of irrigation water management methods (Table 2). Results indicated that the water use efficiency of maize was higher under alternate furrow irrigation method during both seasons as compared with conventional and fixed furrow method. Maximum water use efficiency (1.69 kg/m^3) observed at alternate furrow method was statistically superior to both conventional and fixed furrow methods. The minimum water use efficiency (1.15 kg/m^3) was observed at conventional furrow method and this was statistically inferior to both alternate and fixed furrow method during both seasons (Table 3).

On the other hand, different types of mulch highly significantly ($p<0.01$) influenced maize water use efficiency. Analysis of both years and pooled means revealed that water use efficiency was maximized at plastic mulching than straw and no mulch condition. The maximum water use efficiency (1.72 kg/m^3) obtained at plastic mulching was statistically superior to both straw and no mulch conditions. The minimum water use efficiency (1.26 kg/m^3) was observed at no mulch condition was statistically inferior to both straw and plastic mulching at different irrigation water management methods.

Moreover, highly significant ($p<0.01$) interaction effect was observed between irrigation type and mulch type on improving water use efficiency (Table 2). Maximum water use efficiency was observed at plastic mulching when combined with alternate furrow method. The maximum water use efficiency (2.06 kg/m^3) obtained at plastic mulching under alternate furrow irrigation method was statistically superior to all other treatment combinations which were followed by plastic mulch under fixed furrow irrigation method (Table 4). Significant difference between straw and no mulch was not observed under alternate furrow though straw mulching was significantly higher than no mulch under fixed furrow condition. On the other hand, minimum water use efficiency was associated with higher water

Irrigation type	Mulch type	WUE (kg/m^3)
AF	No mulch	1.47^{c,d}
AF	Plastic	2.06^{a}
AF	Straw	1.54^{c}
CF	No mulch	1.05^{f}
CF	Plastic	1.24^{e,f}
CF	Straw	1.16^{e,f}
FF	No mulch	1.27^{d,e}
FF	Plastic	1.85^{b}
FF	Straw	1.49^{c}
CV (%)	:	8.1
$LSD_{0.05}$	:	0.20

^{a,b,c,d,e,f} Letter with similar letter in the column are not significantly different.

Table 4: Interaction effect of irrigation type with mulch level on water use efficiency of maize.

application in the case of conventional furrow irrigation method. The minimum water use efficiency (1.05 kg/m^3) obtained at conventional furrow irrigation method under no mulch condition. However, all the mulching types under conventional furrow irrigation method were statistically similar in water use efficiency.

The highest water use efficiency obtained at plastic mulching under alternate furrow method was 96.2% higher than the control treatment, no mulch under conventional furrow irrigation method. This might be due to moisture conservation by minimizing evaporation from the soil and alternately wetting all furrows and root zone during successive irrigation in case of plastic mulching under alternate furrow method. This leads to utilize much of the irrigation water for transpiration and nutrient uptake from soil so that the amount of grain obtained per amount of irrigation water applied maximized under limited water condition.

Based on different studies in different location, Montazar and Kosari [11] reported that water productivity of maize could range over 1.17 kg/m^3 with different techniques that enhance water use efficiency like deficit irrigation and mulching. Narayanan and Seid [8] reported that alternate furrow irrigation method with application of 70% irrigation water requirement of maize maximizes water use efficiency. Similarly, El-Halim [22] reported that water use efficiency increased under alternate furrow irrigation method as compared with every furrow irrigation. Based on their findings Nasri et al. [10] concluded that alternate furrow irrigation as a way to save water in arid area where maize production relies heavily on repeated irrigation. Based on the findings their findings Nasri et al. [10] concluded that alternate furrow irrigation as a way to save water in arid area where maize production relies heavily on repeated irrigation.

Similarly, different mulching types lead to maximizing water use efficiency. For example, Mo et al. [13] reported that maize water use efficiency was increased by 53.3% in black plastic mulch than non-mulch condition with alternative ridge and furrow method, respectively. Xu et al. 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, although the overall evapotranspiration was similar between the two treatments [23].

With reduced soil evaporation, the conserved moisture due to plastic mulching might be allotted to transpiration which improves nutrient uptake and transportation to plant body. Based on different studies in a different location, Montazar and Kosari [11] 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. The conserved moisture content of soil in the root zone due to mulching could enhance crop transpiration and nutrient uptake and transportation in the plant body with limited available water. Other than maize, Panigrahi et al. [9] reported that irrigation water use efficiency of okra plant is the highest under black plastic mulching with alternate furrow irrigation method than the conventional furrow condition under different soil moisture depletion levels.

Conclusions

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 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. However, there was no variation between due to different mulching conditions when maize irrigated under conventional furrow (all furrow irrigated) method. Based on our current study, we identified the optimum combination of mulching material and type irrigation water application methods under different irrigation water resource scenario. In conclusion, 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 plastic mulch for improving maize and water productivity in the study area and similar agro-ecology.

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