Crop Water Productivity of Maize under Koga Irrigation Condition

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Abstract

Water is essential for human survival, yet freshwater scarcity threatens growth and food security, making effective water management—particularly deficit irrigation (DI)—crucial. This study examined DI's effects on maize yield, water productivity (WP), and blue water footprint (WF) reduction under different mulches, which apply organic or inorganic materials to soil surfaces to enhance aeration, retain moisture, and curb evaporation. A randomized complete block design (RCBD) with three replications tested three mulches (none, wheat straw, white plastic) and four DI levels: 0% (full irrigation, 100% ETc), 20% (80% ETc), 40% (60% ETc), and 50% (50% ETc), with irrigation scheduled via pan evaporation and data analyzed using ANOVA in R. Results showed significant DI-mulch interactions: 50% ETc DI with plastic mulch minimized consumptive WF reduction and boosted WP by 128.9% over full irrigation without mulch; 80% ETc DI with plastic mulch increased yield by 27.27% over full irrigation without mulch (and 3.17% over 60% ETc with plastic mulch) without significant differences, yielding the highest blue WF (101.433 m^3/ton) for full irrigation without mulch. Marginal rates of return were lowest for 60% ETc without mulch, followed by 80% ETc without mulch, with plastic mulch plus DI preferred by 60% of farmers. These findings advocate DI with plastic mulch to optimize maize production, WP, and WF in water-scarce areas.

Key words: mulch, DI, yield, water productivity, and water management

1. Introduction

Human activities is seriously endangering the water. Freshwater scarcity, a serious issue, is the cause of this. Drier rivers, growing populations, global freshwater withdrawal, socioeconomic development, and population growth are all indicators of a growing water scarcity. In an increasing number of nations across the world, water scarcity has been producing issues (Mekonen, 2022).

A very promising method for accomplishing this objective seems to be the combination of mulching and controlled deficit watering (Abera et al., 2019). Deficit irrigation (DI), which also requires less irrigation, can significantly improve water use efficiency (WUE). Mulching is the process of applying either organic or inorganic materials to the cut soil surface. Mulching can increase aeration, lower evaporation, and retain soil moisture (Igbadun et al., 2012).

The reciprocal of the overall water footprint is called water productivity (WP). The usefulness of WP and WFP depends on the stress and water use situation. Reducing the field evapotranspiration (ET) per unit of yield (Y) during the growing season is the aim at the field level; this ratio is called the consumptive water footprint (WF) (Nouri et al., 2019). Decreasing this ratio ET=Y is the same as increasing the inverse (Y=ET), which is called the water productivity (WP). .

2. Materials and Methods

2.1 Description of the Study Area

The test was done in the 2022/23 irrigation seasons at west gojam. The periodic rain is around 1480 mm at the Merhawi meteorological station. Koga landmark falls under the tropical climate zone. The mean periodic minimum and maximum temperatures are 90^{C} and 320^{C}, independently. The dominant soil type of the area is substantially pale sol with complexion texture(Abera et al., 2019).

2.2 Experimental Design

Three replications of a randomized complete block design (RCBD) were employed. Treatments included three mulching techniques (no mulch, wheat straw mulch, and white plastic mulch) and four deficient irrigation usages (0 (full irrigation), 20 (80 Etc), 40 (60 Etc), and 50 (50 Etc)).

2.3 Design layout and Test Crops spacing

For about a week, the field trial's bed was leveled, smoothed, and somewhat loosened after being furrowed by a tractor and again prepared with effort. The field test's gross area came to 964.65 m² (29.5 m by 32.7 m). There were thirty-six plots in the experimental field. The area of the plot was 14.7 m² (3.5 m × 4.2 m). In order to prevent irrigation water from seeping from one plot to the other plot, blocks and plots were separated by 2 and 1.5 meters, respectively. For every block, a field channel was built to clean the field.

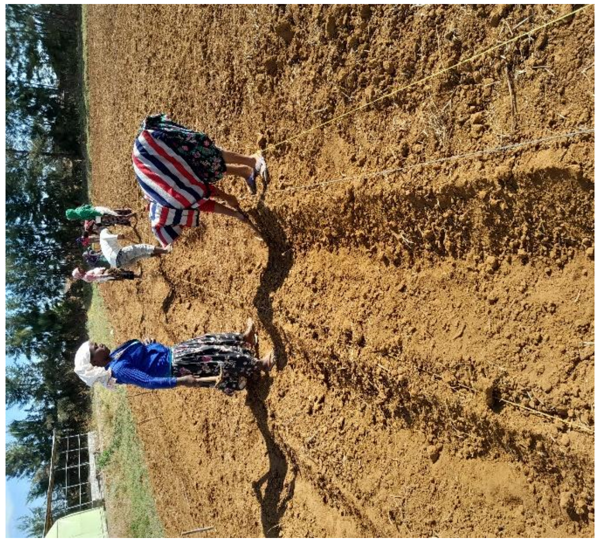

Figure 1 land preparation

2.4 Mulch Application

Due to its local availability, wheat straw was employed as mulch in this study. Once it decomposes, it supplies plant nutrients to soils and also Straw mulching can improve maize growth and development, lower evaporation, and raise soil moisture content, all of which increase grain yield and water usage efficiency (Tao et al., 2015). One month after planting, each plot received a consistent application of 6.67 kg of dried wheat straw mulch at the designated rate, leaving room for the plants. Additionally, 18-micrometer plastic mulch was purchased from the market and applied. The 3.5 m × 4.2 m allotment was covered with 3.8 by4.5

m pieces of white polythene mulch. For every maize crop stand, a tiny hole was cut in the polythene.

Figure 2 mulches application

2.5 Pan method of measuring evaporation at field

Measuring evaporation rates (mm/day) requires the use of evaporation pans, such as the popular Class A circular pans. Under the assumption of no rainfall, they work by establishing a correlation between the rate of evaporation and the gradual decrease in water depth. The combined impacts of wind, temperature, and sun radiation on open water surfaces are measured by these pans. Evaporation from water surfaces and farmed areas differ significantly for a number of reasons, even though they replicate the effects of these factors on crop transpiration. Solar radiation is one important factor. Generally speaking, the shallow pan of water reflects roughly 23% of solar radiation; this value is frequently taken for reference surfaces made of grass.

Figure 3 pan evaporation pan from site

2.6 Estimation of crop water demand

The crop water requirement for maize crops over the growing season was determined from the relationship between pan evaporation (Ep) with Kc and Kp values based on the percent growing season used to determine ETC (Allen, 1998). The calculations of the crop water requirements (CWR) use the crop coefficient approach. Potential evapotranspiration (ETO) was determined from pan evaporation data. U.S. class A pan was installed near the research site to record daily pan evaporation. The pan evaporation method measures the evaporation from the open water surface, taking into account the cumulative effect of radiation, wind, humidity, and temperature. The daily pan evaporation is measured from the pan, and then the weekly average evaporation is multiplied by the kc value based on the growth stage listed below. Then after that, take furrow irrigation efficiency to 70%. After we get it, multiply by plot area.

$$ETc\ pan = Kc * Kp * Epan ---------- Equ\ 2.1$$

2.7 The blue water footprint of growing crops

The blue WF (m3/t) of crops was obtained following the definitions and methodological framework of the global WF accounting standard (Zhuo & Hoekstra, 2017). It was calculated by dividing the blue water crop water requirement (m3/ha) over the growing season by the marketable crop yield (kg).

2.8 Soil moisture data

The most useful metric for assessing weather, hydrological, agricultural, and climate-related events was soil moisture. Its spatial and transient fluctuations are due to the fact that it was crucial to the information about soil moisture. Such intriguing data can be crucial for a variety of weather-related judgment agencies, including growth characteristics, crop yield estimation, and climate. Due to the difficulty of gathering soil moisture data, soil moisture was highly dynamic in both space and time. A probe device was used to determine the average moisture content of the experimental sites both before and after irrigation. As a result of this, I have to install 27 probe instruments to measure soil moisture at different depths, starting from 10 cm up to 1 m at each 10 cm difference to take soil moisture data.

Figure 4 installing probe instrument

2.9 Crop data

The cobs were taken from the plants in each plot, unsheathed, sun-dried for a week, shelled, and weighed before being converted on a hectare basis to determine the grain yield for maize, which was then corrected to 12.5% moisture content.

2.10 Computation of water productivity

The output (such as crop yield) in relation to the water input in agricultural production was referred to as crop water productivity. The output was measured in terms of physical yield, while the water input might come from seasonal transpiration, seasonal evapotranspiration, or seasonal field application. In this study, crop water productivity is defined with respect to yield and seasonal water supply, and the expression is given as(District & Gebreigziabher, 2000) analyzed this author:

CWP (irrigation) (kg/m3) = Crop yield (kg/ha) /Seasonal irrigation water applied (m)

2.11 Partial Budget Analysis

Input costs (seeds and mulches), labor costs (land preparation, seeding, mulching applying, irrigation, insect control, harvesting) and the market price of dry grains of the corresponding common maize varieties at harvest were among the economic benefits data collected. The profitability of plastic mulch with different irrigation depth, wet straw mulch with different irrigation depth and no mulch with different irrigation depth was calculated using partial budget analysis which was calculated as grain yield (kg/ha) multiplied by the dry grain yield and price that farmers received for the crop's sale per kg. Unit price of plastic mulch is 3 birr per m2, unit price of wet straw mulch is 2.5 birr per m2, unit price of dry yield is 20birr/kilogram and unit price of labour cost price is 110birr per person. Total variable cost (TVC) was calculated as the sum of all variable production expenses incurred on the farm except fixed price like fertilizer cost, initial land preparation cost, seed cost, spraying of agro lambency, applying of irrigation water to a plot and other fixed cost was not include.

The calculation of net benefit (NB) or marginal return (MR) was done by deducting the total variable costs from the total income. The marginal rate of return (MRR) was determined by dividing the difference between the net benefits of successive treatments and the difference between the total variable costs of successive treatments explained by this researcher (Jemal & Agegnehu, 2020).

2.12 Data Analysis

Using the R software, agronomic parameters were statistically examined using analysis of variance (ANOVA). At a 5% probability level, the variation between treatments was compared with the least significant difference.

3. Result

3.1 Yield

The combination of 20% deficiency irrigation levels (80%ETc) with plastic mulch produced the highest yield (5908.733 kg/ha). There was a numerical variation in the yield, but the yields of deficit irrigation levels (60%ETc) with plastic mulch and deficit irrigation levels (80%ETc) with plastic mulch treatment combination were recorded with nearly equal yield values and no superior interaction effect on the yield. Because plastic mulch controls soil temperature by keeping it cooler in the experimental field, retaining nutrients, lowering evaporation, and retaining water in the soil coated with this concept, the maximum yield was reported at deficit irrigation levels (Hoekstra et al., 2011) reported similarly with my research, explaining soil temperature modification and reduction of evaporation.

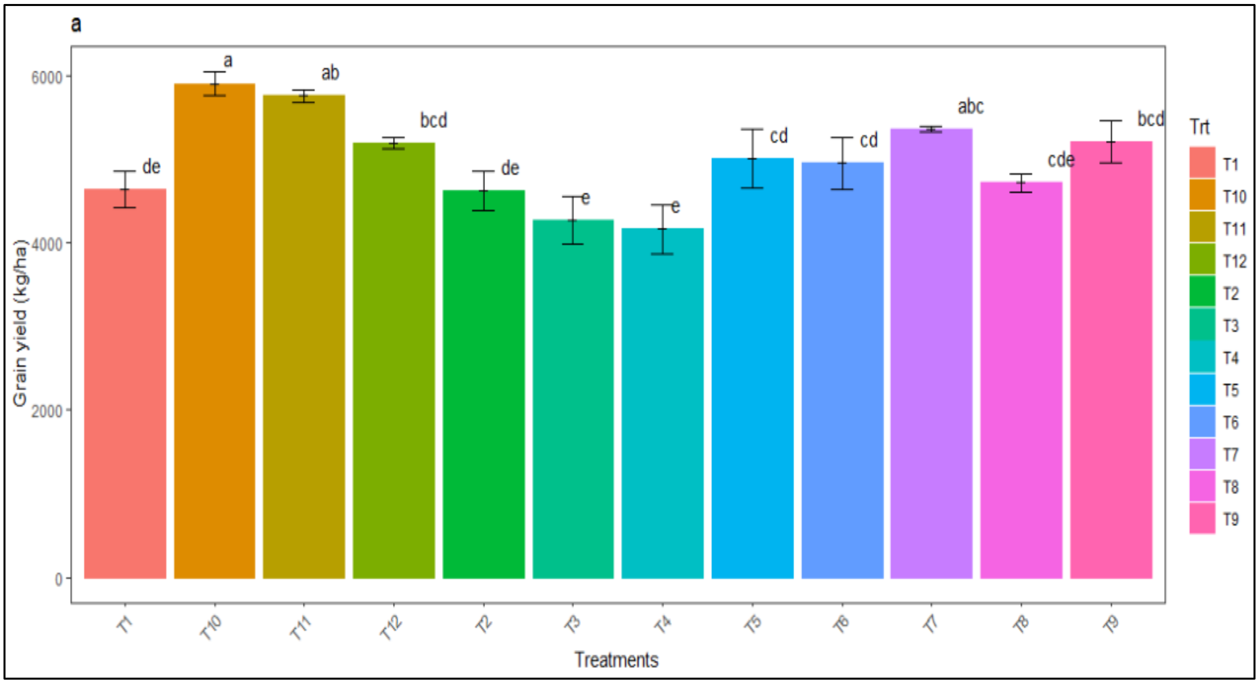

Figure 5 graphical representation of yield

Table 1 result of yield

Treatments	yield (kg/ha)
80%ETc with pm	5908.7[a]
60%ETc with pm	5761.6[a]
60%ETc with wm	5362.3[b]
100%ETc with pm	5215.4[bc]
50%ETc with pm	5192.6[bc]
100%ETc with wm	5017.9[bcd]
80%ETc with wm	4954.5[cde]
50%ETc with wm	4722.5[de]
100%ETc with nm	4642.6[def]
80%ETc with nm	4628.8[ef]
60%ETc with nm	4277.9[fg]

50%ETc with nm	4167.8^{g}
CV	4.59
P-level	*
LSD(0.05)	387.8

3.2 The resulting effect of mulch types and deficit irrigation levels on water productivity

The combined treatment effects of mulch kinds and deficit irrigation levels had a highly significant impact on water productivity ($p<0.05$). The combination of plastic mulch treatment with deficit irrigation level (50%ETc) produced the highest water productivity (2.2 kg/m³). This outcome matched Yaseen et al.(2014) and Abera et al.(2019).

Table 2 water productivity

Treatments	water productivity (kg/m^3)
50%ETc with pm	2.22a
60%ETc with pm	2.03b
50%ETc with wm	2bc
60%ETc with wm	1.9c
50%ETc with nm	1.76d
80%ETc with pm	1.56e
60%ETc with nm	1.53e
80%ETc with wm	1.3f
80%ETc with nm	1.23f
100%ETc with pm	1.06g
100%ETc with wm	1.06g
100%ETc with nm	0.97g

3.3 The resulting effect of mulch types and deficit irrigation on blue water footprint reduction

The interaction effects of various deficit irrigation levels and mulch kinds had a substantial impact on the consumptive blue water footprint reduction ($p<0.05$). The treatment combination of deficit irrigation level (50% ETC) with plastic mulch showed the least reduction in consumptive water footprint. This result was in line with previous research reports (Chukalla et al., 2015).

Table 3 water footprint reduction

Treatments	blue water footprint reduction (%m^3/kg)

100%ETc with nm	101.43[a]
100%ETc with wm	94.03[b]
100%ETc with pm	90.33[b]
80%ETc with nm	81.40[c]
80%ETc with wm	76.13[c]
60%ETc with nm	66.17[d]
80%ETc with pm	63.7[d]
50%ETc with nm	56.6[e]
60%ETc with wm	52.63[ef]
50%ETc with wm	49.8[fg]
60%ETc with pm	49[fg]
50%ETc with pm	45.3[g]

3.4 Partial Budget Analysis

Fixed price like fertilizer cost, initial land preparation cost, seed cost, spraying of agro lambency, applying of irrigation water to a plot and other fixed cost was not include to calculate partial budget analysis. To calculate partial budget analysis I am going to use only varied cost for treatment. These variable cost including weeding cost, cost of mulch and cost of applied irrigation water. The highest overall variable costs were associated full irrigation (100ETc) with plastic mulch, which was followed by depth of depth of irrigation 80%ETc with pm, 100%ETc with wm and 60%ETc with pm. The depth of 80%ETc with pm has more net benefits and income than any other treatment combination like depth of deficit irrigation with wet straw mulch, plastic mulch and no mulch treatment. Different mulch techniques had varying marginal cost, marginal benefit and marginal rates of return; each indicator indicated varying degrees of economic effectiveness Table 4. The no mulch treatment with DI was shown to have a low marginal cost, marginal net benefit and marginal rates of return across all treatments, while plastic mulch with DI had almost better marginal rate of returns than wet straw mulch with DI. When compared to all mulch types with DI and the control with DI, plastic mulch with DI (80%ETc) had the highest marginal rate of return (2190.6), followed by 60%ETc with pm and 60%ETc with wet straw mulch. The lowest marginal rate of return depth of irrigation 60%ETc with nm followed by depth of irrigation 80%ETc with nm. Plastic mulch with DI had showed better marginal rates of return.

Table 4 partial budget analysis

Treatment	Yield (kg/ha)	Income (birr/ha)	Total variable cost(birr/ha)	Net benefit (birr/ha)	MRR (%)
50%ETc with nm	4167.8	83356	27205.55	56150.45	0
60%ETc with nm	4277.9	85558	28616.66	56941.34	56.04737
80%ETc with nm	4628.8	92576	31438.88	61137.12	148.6695
100%ETc with nm	4642.6	92852	34261.1	58590.9	D
50%ETc with wm	4722.5	94450	34705.55	59744.45	259.5455
60%ETc with wm	5362.3	107246	36116.66	71129.34	806.8039
50%ETc with pm	5192.6	103852	38305.55	65546.45	D
80%ETc with wm	4954.5	99090	38938.88	60151.12	D
60%ETc with pm	5761.6	115232	39716.66	75515.34	1975.394
100%ETc with wm	5017.9	100358	41761.1	58596.9	D
80%ETc with pm	5908.7	118174	42538.88	75635.12	2190.622
100%ETc with pm	5215.4	104308	45361.1	58946.9	D

4. Conclusions and Recommendation

The purpose of this study was to assess the impact of mulch types and deficit irrigation on crop water productivity, yield, and yield component. In order to examine the impact of deficit irrigation (DI) and mulch types on yield component, yield, and crop water productivity, a field experiment was carried out using varying DI levels and mulch kinds. The important aspect of this study was determining which of the 12 treatment combinations was acceptable by the community, particularly in the region with vulnerable, little rainfall. Additionally, determining which treatment combination produced the best results in terms of crop water output and productivity. In generally this results of experiment indicate that the application of mulch types and deficit irrigation (DI) methods was the most special irrigation technique in the area where there is limited rainfall.

The study assesses how different types of mulch and deficit irrigation (DI) affect crop water productivity and output. In order to examine different DI levels (50%, 60%, 80%, and 100%ETc) and different types of mulch (plastic mulch, organic mulch, and no mulch), the research uses a field experiment. The main results show that yield and water savings are maximized when plastic mulch and DI are coupled at 60% ETc. According to the study, combining DI with mulching increases crop water productivity, yield, yield component, and soil moisture retention while lowering evaporation.

Additional findings about yield, particularly plastic mulch with DI that lowers irrigation water use, are expressed as follows. Water consumption is decreased by DI and mulch kinds. The best production was observed at deficit irrigation levels of 60% ETC and 80% ETC with plastic mulch. With a 20% ETC water applied differential between the two treatment combinations, the recommended deficit irrigation level (60% ETC) with plastic mulch is the method of water conservation. The combination of plastic mulch treatment with deficit irrigation level (50% ETC) produced the highest water productivity (2.2 kg/m^3). This suggested that DI with plastic had higher water production. All deficit irrigation levels with different types of mulch, however, showed improved water productivity and yield. Consequently, in regions where water is scarce, the water conserved could be utilized to cultivate more land. Grain yield, plant height, cob length, cob width, leaf length, leaf breadth, and water productivity were all equivalent in plots that received water irrigation using the deficit irrigation and mulches type approach.

4.1 Recommendation

In order to maximize crop water productivity and achieve the highest yields of maize, farmers and extension agents are recommended to use deficit irrigation techniques with mulch types, which apply plastic mulch at a depth of deficit irrigation level (60%ETc) throughout growth phases while conserving 40% of the water required.

The results indicate that when compared to non-mulched areas, mulching varieties are superior at conserving water while simultaneously enhancing yield production. Farmers must so use this method, particularly in arid and semi-arid areas where water scarcity is a serious problem and conflicts between irrigators upstream and downstream are a big concern.

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