JOURNAL OF INNOVATIVE RESEARCH (JIR)

ISSN: 2837-6706 (Online)

VOLUME 2 ISSUE 3 (2024)

PUBLISHED BY
E-PALLI PUBLISHERS, DELAWARE, USA

Journal of Innovative Research (JIR)

Volume 2 Issue 3, Year 2024
ISSN: 2837-6706 (Online)
DOI: https://doi.org/10.54536/jir.v2i3.2836
https://journals.e-palli.com/home/index.php/jir

Effect of Plastic and Organic Mulching on Soil Moisture Retention and Yield Response of Tomato under Furrow Irrigation

Fekadu Gemeda[1*], Bayan Ahmed[1], Asnake Tilaye[1], Negash Badeso[1]

Article Information

Received: July 18, 2024

Accepted: August 21, 2024

Published: August 24, 2024

Keywords

Mulching, Soil Moisture Retention, Water Use Efficiency, Water Productivity

ABSTRACT

One of the main causes of the low yield of tomatoes and low-quality products in Ethiopia's Rift Valley is insufficient soil moisture during the crop-growing season. To overcome this challenge, a field trial was carried out at Tiyo woreda of Ketar Genat kebele to examine the effects of mulching and irrigation levels on soil moisture retention, water use efficiency, water productivity, and the yield of Halila variety tomatoes to determine the most efficient net return. The treatments were factorial design consisting of four mulching materials (white plastic, black plastic, wheat straw mulch, and no mulch) as the main plot and two water levels (100% ETc and 75% ETc) as sub-plot used with three replications. The interaction irrigation method and mulching types were highly significant at $p<0.05$ on soil moisture retention, water use efficiency, water productivity, and yield. The experiment's findings showed that the interaction effect of white plastic mulch with 100%ETc produced the highest soil moisture retention, marketable yield, and total yield; however, it ranked fourth in WUE. The second was white plastic mulch with 75% ETc but was WUE, and the benefit-cost ratio was the first. The last was recorded at non-mulch. Therefore, based on the results of eight treatments in the experiment for tomato production, a combination of WPM with 75% ETc was advised for irrigation water management in keytar Genet Kebele and its surroundings and other similar agroecologies.

INTRODUCTION

Tomato (*Lycopersicon esculentum L.*) is one of the most important vegetables all over the world, and the dominant vegetable crops in Ethiopia are mostly grown under irrigation for their edible fruits and nutritional values(Berihun, 2011). In Ethiopia, tomato ranks fourth in total production (5.45%) after cabbage, red pepper, and green pepper. Its national mean yield is 6.2 tons/ha(CSA, 2015; Regassa *et al.*, 2016). This is by far below the world average of 34.84 tons/ha, which is due to different factors (Getachew & Gemechu, 2019). One of the reasons for the low productivity of tomatoes is very sensitive to soil–water conditions, as water stress (drought and flooding) leads to a serious reduction in the yield and quality of fruits (Regassa *et al.*, 2016; Vaddevolu *et al.*, 2021).

Mulching has become an important practice in modern field production. The use of mulches in vegetable production is undergoing a radical change in soil moisture conservation by using different mulching materials materials, such as nonrenewable materials like plastic and organic materials like the use of high-residue organic mulches from crop covers (Kundu *et al.*, 2019). The application of mulching material significantly influences tomato plant growth, fruit yield, and root zone soil temperature (Habtamu *et al.*, 2016). The research reported that water directly affects the tomato yield, as it contains 94% water. More than 485 mm of water is required for successful crop production during plant establishment, flowering, fruit setting, and fruit development stages (FAO, 1995).

In water-stressed areas, there is a problem of long irrigation frequency due to competition for irrigation water between communities, and the irrigation field is dried out before the next irrigation. This situation is harmful to plant growth and yield. For such a challenge, mulching is a key strategy for extending the period of soil moisture and conserving irrigation water until the next round of irrigation is done.

Mulching has been reported to be increased yield by creating favorable soil temperature and moisture regimes (Habtamu *et al.*, 2016,). Mulching is an effective method of manipulating crop growing environment to increase yield and improve product quality by controlling weed growth, ameliorating soil temperature, conserving soil moisture, reducing soil erosion, improving soil structure, and enhancing organic matter content.

Therefore, this study was carried out to determine soil moisture retention, water use efficiency, and yield response of halila tomato on two water levels and three mulching types under furrow irrigation to overcome irrigation water shortage and increase water use efficiency.

MATERIALS AND METHODS

Study Area

The study was conducted from 2020 to 2022 at Arsi Zone, Tiyo worada of Ketar-Genat Kebele during the dry season when the crops were being cultivated under irrigation. Ketar-Genet is located approximately 214 km from Addis Ababa, the capital of Ethiopia, and 39 km from Asella, the zonal capital city. It is situated between latitudes 7050'30''N and 70 51'0''N and longitudes 3901'0''E and 390 2'0''E.

[1] Oromia Agricultural Research Institute, Asella Agricultural Engineering Research Center, P.O Box 6, Asella. Oromia. Ethiopia
[*] Corresponding author's e-mail: firogemeda07@gmail.com

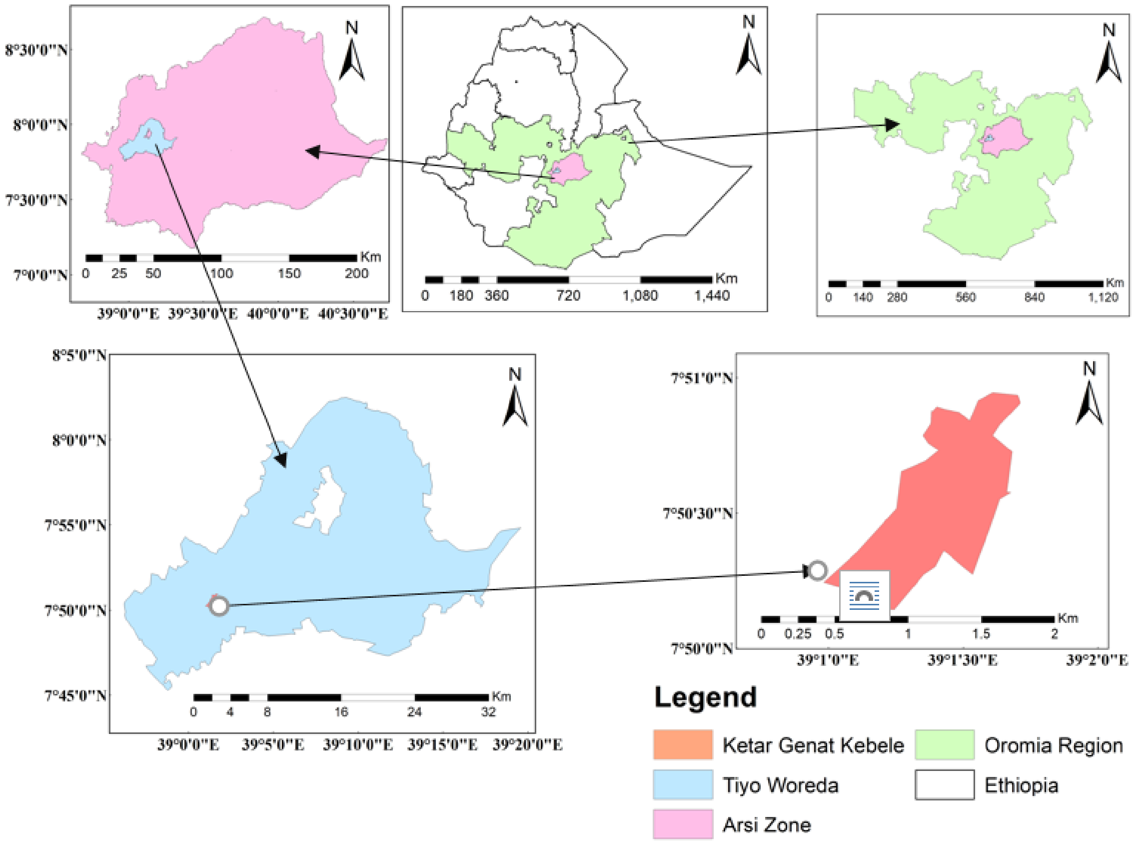

Figure 1: Map of the study area

Experimental Design and Treatments

The experiment had two factors namely, two water levels and four mulching techniques were used with factorial design under three replications. The two water levels (100 %ETc and 75% ETc) were used as the sub-plot whereas mulching materials (white plastic, black plastic, wheat straw mulch, and no mulch) were used as the main plot.

Preparation of the Experimental Area

The experimental plot's total area was 1080 m³ (45 m*24 m), and as shown in figure 2, it was subdivided into 24 sub-plots, each measuring 27 m2 (4.5 m * 6 m). The width of each ridge was kept at 0.45 m, ridge to ridge distance was 0.50 m, and furrow spacing of 0.70m. The ridges were covered with polyethylene plastic sheets (0.5 µm thick) and wheat straw mulch while furrow beds were kept uncovered. The plots and replications plot had a buffer zone of 1m and 1.5m between plots on non-supplying and supplying canal sides, respectively to eliminate the influence of lateral sub-surface water movement.

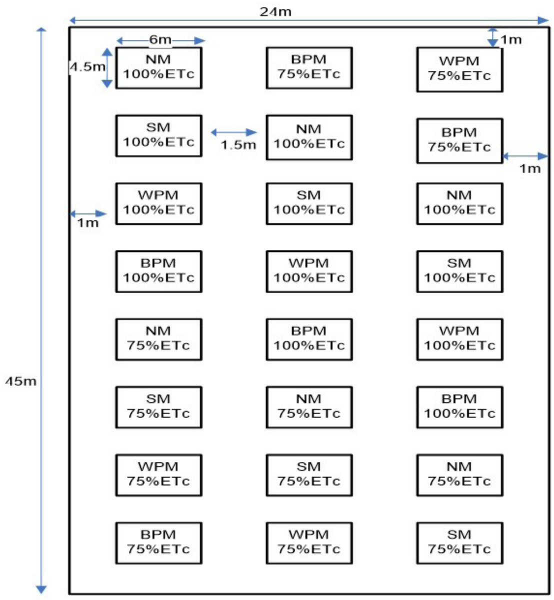

Figure 2: Experimental field layout of plot and randomization

Crop Management Practices and Application of Fertilizer

The experimental plots were pre-irrigated three days before planting. Each treatment in a plot consisted of eight rows with a total number of 88 plants per plot. After placing the plastic film on the ridge, the tomato crops were planted at a spacing of 40 cm distance. But in the case of straw mulching the crops were planted on ridge before straw mulching. The recommended rate of NPS and urea were uniformly applied to the plots through perforation or sowing in the furrow before irrigation. NPS was applied at planting time only and urea was applied in Split application, half at planting and another half twenty days after planting. Light irrigations were applied before the start of treatment applications for seven days. Water applications for control treatment or full irrigation (100%ETc) were based on the estimated crop water requirement calculated over the growing period and water deficit treatments 75%, were imposed as planned. In furrow irrigation, each plot was irrigated using a Parshall flume.

Figure 3: Experimental field layout of mulch

Soil Sampling and Analysis

Composite soil samples were collected and analyzed to characterize the soil of the study area. The bulk density, moisture content at field capacity (FC), permanent wilting point (PWP), and organic matter content (EC) of disturbed and undisturbed soil samples were taken diagonally using an auger and core sampler at a depth of 0–30 cm and 30–60 cm for laboratory analysis.

The USDA textural triangle was used to determine the textural class in the textural analysis of the soil, while the hydrometer method was used for analyzing the distribution of particle sizes. The titration method was used to determine the soil's organic matter content. To find the carbon content, the soil was oxidized using potassium dichromate in sulfuric acid under controlled conditions. By multiplying the carbon content by 1.724, the organic matter content status was determined (Walkley and Blank, 1934).

After a 24-hour oven drying process at 105°C, the samples were weighed to determine the dry density and the bulk density of the soil was determined as given by Michael, (2008).

$$\varrho_b = Ms/Vt \quad (1)$$

Where: ϱ_b soil bulk density (gm/cm^3)

Ms=mass of dry soil (gm) and

Vt =total volume of soil in the core sampler (cm^3)

A PH metre was used to measure the pH of the soil using a water suspension of a soil-to-water ratio of 1:2.5. Water suspension method with a soil to water ratio of 1:2.5 was used to determine EC by electro conductivity meter.

Using the pressure plate apparatus, soil samples were saturated for one day (24 hours) in order to determine the soil moisture content at field capacity (FC) and permanent wilting point (PWP). A pressure of 0.33 bars was used to determine the field capacity, and a pressure of 15 bars was used to determine the permanent wilting point until no change in moisture was observed. Total available water (TAW) was also calculated using the FC and PWP values. Three soil samples from each plot were used for the parameter test. As stated by Allen *et al.* (1998), TAW was also determined after FC and PWP were determined.

$$TAW=((FC-PWP)*\varrho_b*D)/100 \quad (2)$$

Where: TAW = total available water (mm)

FC = field capacity (% by weight)

PWP = permanent wilting point (% by weight)

D = depth of root zone (mm)

For maximum crop production, the irrigation schedule was fixed based on readily available soil water (RAW). The RAW was the amount of water that crops can extract from the root zone without experiencing any water stress. The RAW was computed from the expression:

$$RAW = TAW * MAD \quad (3)$$

Where: RAW is readily available water and MAD is management allowable depletion normally varies from 0.3 to 0.7 depending on soil type.

Climatic Data

In order to calculate mean daily reference evapotranspiration (ETo), the National Meteorological Agency provided the necessary parameters, which included the study area's minimum and maximum temperature, relative humidity, wind speed, and daily sunshine hour for 30 years.

Crop Water Requirement and Irrigation Water Requirement

The reference evapotranspiration (ETo) of the study area was determined by feeding climatic, soil, and crop data into CROPWAT version -8.

ETc = ETo x Kc (4)

Where: ETc = crop evapotranspiration (mm/day)

ETo = reference crop evapotranspiration (mm/day)

Kc = crop coefficient

The crop's net-irrigation requirement was calculated based on the cropping pattern. Using the crop's net-irrigation requirement, irrigated areas, and irrigation efficiency, the total amount of water needed for irrigation was determined.

The irrigation interval was computed as;

$I = d_{net}/ET_c$ (5)

Where I = irrigation interval (days)

d_{net} = net-depth of irrigation (mm)

ET_c = daily crop evapotranspiration (mm/day)

For a given crop, soil, and climate, the depth of irrigation application refers to the amount of water that can be stored in the root zone between the field capacity and the permanent wilting point of the soil water depleted. It is equivalent to the soil water that is readily available over the irrigated area. By calculating the bulk densities and contents at field capacity for each soil layer, one can find the moisture deficit (d) in the effective root zone (Mishra and Ahmed, 1990).

(Mishra and Ahmed, 1990).

$d = \sum^{n}_{(i=1)}((FC_i - PWP_i) * \gamma_i * D_i * P)/100$ (6)

Where: FC_i = field capacity of the irrigation water layer on oven dry weight basis (%)

PWP_i = Actual moisture content of the water layer on oven dry weight basis (%)

γ_i = apparent specific gravity of the soil of the irrigation layer

D_i = depth of the irrigation layer (mm)

P= depletion fraction (%)

n= number of layers in the root zone

Soil Moisture Measurement

Gravimetric analysis was used to determine the moisture content of the soil. For this soil, samples were taken from the field at two different soil depths (0–30 cm and 30–60 cm) both before and after irrigation. Samples were obtained within the effective root zone at intervals of 30 cm. Before and after each irrigation event, the soil profile's moisture status was assessed for every field. A soil auger operated by hand was used to take the samples. Before placing it in an oven to dry at 105°C, the soil sampler was weighed and placed in an airtight container. Although a constant dry weight (less than 0.1% change in an hour) is typically achieved before this, the sample was left in the oven for 24 hours (Walker, 2003) and the moisture was calculated as a percentage of the dry weight of the soil sample (W) as.

W= (Mt - Ms)/Ms =Mw/Ms * 100 % (7)

Where: W=weight of soil sample (gm)

Mt=weight of fresh sample (gm)

Ms=weight of over-dried sample (gm)

Mw= weight of moisture (gm)

To convert these soil moisture measurements into volumes of water, the volumetric moisture content (θ) was calculated as

$\theta = (\varrho_b * W)/\varrho_w$ (8)

Where: θ = volumetric moisture content (%)

ϱ_b = Soil bulk density (gm/cm^3)

W = moisture content on dry weight basis (%)

ϱ_w = unit weight of water ($1gm/cm^3$)

Discharge Measurements at the Field

A 3" (3 inch) parshall flume was used to measure the water flow into the experimental flow and was placed at the entrance. The measurement of discharge was made at 2/3A, or two-thirds of the converging section's length. The corresponding discharge for a 3" parshall flume was then calculated using equation (9) based on the flow depth that was observed on the flume. The total depth of applied water was then determined using the representative plot, and the total volume of applied water (Va) was computed using equation (10) as stated (James, 1988).

$Q = C_f * (KH)^{nf}$ (9)

For 3" parshall flume,

$Q = 0.177H^{1.55}$ (10)

Va= Q * Δt (11)

Where: Q= discharge through the flume (l/s)

Cf= discharge coefficient from rated tables

K = unit constant (K= 3.28 for H in m)

nf =flow exponent from the tables

Va = total volume of water applied (m^3)

Δt =flow time to the field

The amount of time required to deliver the appropriate depth of water into each furrow was calculated using the equation recommended by Israelsen (1980).

t= (d * w * l)/(q * 60) (12)

Where; d= gross depth of water applied (cm), t= application time (hr), l= furrow length in (m), w= furrow spacing in (m), q= flow rate (l/s)

Water Productivity

Water use efficiency (kg/ha, kg/m^3, or q/ha) is a common way to describe how much water a crop uses (Michael, 1997). By dividing the yield by seasonal ET and the total amount of seasonal irrigation water (IW) applied, water use efficiency (WUE) and irrigation water use efficiency (IWUE) can be calculated (Tanner and Sinclair, 1983).

WUE= Ya/ETc (13)

Where: WUE = water use efficiency (kg/m^3)

Ya = is the actual yield (kg/m^2)

ETc = seasonal crop evapotranspiration (m^3/m^2)

IWUE=Ya/IW (14)

Where, IWUE- irrigation water use efficiency (kg/m^3)

Ya - actual yield (kg/m^2)

IW - irrigation water applied (m^3/m^2)

Economic Analysis

Economic analysis was computed by using the results of this study based on investment, operation, and production costs. Based on the irrigation amount of each treatment in the growing season; irrigation duration and labor cost were estimated. The mean tomato yield (kg ha-1) was adjusted for yield losses by subtracting 10% of the tomato yield from total yield

The production costs were computed by considering all production inputs (i.e. cost of seeds, cost of mulch material, plowing of land, transplanting, cultivating, weeding, pesticide application, fertilizer, and harvesting). Finally, the adjusted yield was multiplied by the field price to obtain the gross field benefit of the tomato. The field price of tomato during the harvesting season was 20 Birr kg-1 and a 3.8 Birr m-3 value for water was taken. The benefit-cost ratio was calculated by dividing net benefit by total cost (Jansen *et al.*, 2007).

Statistical Analysis

The collected data were statistically analyzed using Statistic version 8.0 and a statistical package using ANOVA. Mean comparisons were performed using least significant difference (LSD) at 5% probability level.

RESULT AND DISCUSSION

Physio-Chemical Properties of Soil

Table 1 below shows the soil particle size property of the study area. The average particle size of sand, silt, and clay soil was 28, 33, and 39% respectively. The soil textural class of the study site falls under clay loam according to USDA (1998) and Chandrasekaran *et al.*, (2010).

Table 1: Analysis of the experimental site's soil pH, EC, OMC, and texture

Samples	Soil texture			
	Sand %	**Silt %**	**Clay %**	**Class**
1	24	25	51	clay
2	24	35	41	clay
3	24	43	33	clay loam
4	30	32	38	Clay loam
5	26	36	38	clay loam
6	25	37	38	clay loam
7	34	24	42	clay
8	30	36	34	clay loam
9	36	30	34	clay loam
Average	**28**	**33**	**39**	**clay loam**

The physio-chemical properties of the study area are displayed in Table 2 below. The pH values of this soil ranged from 5.51 to 7.40, with an average of 6.02. This suggests soil that is somewhat acidic. At room temperature (25°C), the electrical conductivity (EC) of the stations ranged from 0.11-0.40 mmhos/cm. The study area's class of soil texture was clay loam. pH, electrical conductivity, and organic matter had average values of 6.02, 0.2, and 3.49, respectively.The average density, FC, PWP, and TAW of the study site were 1.29 g/cm3, 49.30%,32.42 %, and 168.82 mm/m respectively. The result of soil density and TAW were fallen at intervals of clay loam soil. According to Classes of salinity and EC (1dS/m = 1 mmhos/cm; as adapted from USDA (1998), soil which has electrical conductivity <0.2 mmhos.cm is non-saline soil.

Table 2: Soil pH, EC, OMC, and texture determination of experimental site

Samples	PH	EC (mmhos/cm at 25°C)	OC %	OM	Bulk density (g/cm3)	FC (% Vol)	PWP (%Vol)	TAW (mm/m)
1	6.50	0.13	1.66	2.87	1.22	49.19	33.15	160.40
2	6.20	0.14	2.38	4.10	1.31	53.90	33.00	209.00
3	6.30	0.15	2.54	4.38	1.33	48.90	32.10	168.00
4	7.40	0.40	1.17	2.01	1.29	45.90	30.00	159.00
5	5.34	0.24	2.04	3.52	1.28	48.40	34.00	144.00
6	6.03	0.21	2.19	3.77	1.30	52.00	30.90	211.00
7	5.39	0.32	1.98	3.41	1.20	47.7	31.88	158.20
8	5.57	0.11	2.15	3.71	1.35	48.1	33.80	143.00
9	5.51	0.11	2.13	3.67	1.31	49.6	32.92	166.80
Average	**6.02**	**0.2**	**2.02**	**3.49**	**1.29**	**49.30**	**32.42**	**168.82**

Interaction Effect of Mulch and Water Level on Soil Moisture Retention Yield and Water Use Efficiency of Tomato

Table 3 shows the interaction effect of mulch and water level on yield and water use efficiency of tomatoes. The total yield of tomatoes was 53.88-64.03 tone/ha. The result yield agreed with the average yield of Galilae 57.9 tone/ha (Tesfa *et al.* 2016). The soil moisture retention of WPM with 100%CWR was the highest and significantly different from other mulch and water level interactions. The next was WPM*75%CWR but not significantly different from BPM*100%CWR. The lowest was NM*75%CWR. The highest branch per plant was registered in WPM*100%CWR but not significantly different from WPM*75%CWR. The next was BPM*75%CWR and the lowest was NM*75%CWR. The highest marketable yield of tomato was registered at WPM*100%CWR. The WPM*75%CWR, BPM*100%CWR, and BPM*75%CWR were the second, third and fourth respectively. The lowest yield was NM*75%CWR. The highest water use efficiency was recorded at WPM*75%CWR but not significantly different from BPM*75%CWR. The last was SM*75%CWR

Table 3: Interaction effect of mulch and irrigation water level on soil moisture retention, yield component, and water use efficiency of tomato

Treatment	SMR	BPP	NFP	MY	UY	TY	WUE
WPM*100%CWR	40.09^{A}	5.44^{A}	35.11^{A}	55.17^{A}	8.86^{A}	64.03^{A}	12.95^{D}
WPM*75%CWR	34.93^{B}	5.22^{A}	30.78^{B}	52.34^{BC}	8.30^{A}	60.643^{B}	16.35^{A}
BPM*100%CWR	35.66^{B}	4.78^{B}	31.56^{B}	52.86^{B}	8.54^{A}	61.41^{B}	12.41^{E}
BPM*75%CWR	32.07^{C}	4.34^{C}	29.22^{BC}	51.60^{C}	8.09^{A}	59.69^{B}	16.09^{v}
SM*100%CWR	31.33^{C}	4.01^{D}	26.22^{CD}	49.53^{D}	7.73^{AB}	57.26^{C}	11.57^{F}
SM*75%CWR	28.23^{D}	3.68^{E}	22.33^{E}	48.30^{E}	7.73^{AB}	56.08^{CD}	15.12^{B}
NM*100%CWR	28.12^{D}	3.50^{E}	25.33^{DE}	48.34^{E}	6.53^{B}	54.87^{DE}	11.09^{F}
NM*75%CWR	24.79^{E}	3.10^{F}	22.20^{E}	47.13^{F}	6.75^{B}	53.88^{E}	14.52^{C}
S.Em±	0.87	0.1196	1.5773	0.53	0.61	0.89	0.23
CV	3.33	3.44	6.94	1.29	9.53	1.87	2.01
LSD (5 %)	1.86	0.2565	3.39	1.14	1.31	1.92	0.48

Where SMR Soil Moisture Retention, BPP Branch per Plant, My marketable yield, UY Unmarketable, TY Total Yield, WUE Water Use Efficiency

Cost-Benefit Analysis

From Table 4 the cost-benefit ratio of WPM*75%Etc was the highest. The result was agreed with (Ali *et al.*, 2019) the of plastic much-increased yield and net benefit

Table 4: Cost-benefit analysis

Treatment	Total yield (kg/ha) (a)	Adjustable yield (kg/ha (b)=(a)-(a)*0.1	Total cost (ETB/ha) (c)	Grand benefit (ETB/ha) (d)=20*(b)	Net benefit (ETB/ha) (e)=(d)-(c)	Benefit cost ratio (f)=(e)/(d)
WPM*100%CWR	64000.0	57600.0	74,620	1152000	1077380	14.44
WPM*75%CWR	60600.0	54540.0	55,965	1090800	1034835	18.49
BPM*100%CWR	61400.0	55260.0	74,620	1105200	1030580	13.81
BPM*75%CWR	59700.0	53730.0	55,965	1074600	1018635	18.20
SM*100%CWR	57300.0	51570.0	69,620	1031400	961780	13.81
SM*75%CWR	56100.0	50490.0	52,215	1009800	957585	18.34
NM*100%CWR	54900.0	49410.0	67,620	988200	920580	13.61
NM*75%CWR	53900.0	48510.0	50,715	970200	919485	18.13

CONCLUSION

Application of mulching material can potentially conserve soil moisture by reducing evaporation losses, and increasing water use efficiency and yield of tomato. From the findings of this experiment, the highest soil moisture retention, marketable, and total yield were obtained during the interaction of white plastic mulch with 100%CWR but WUE was the fourth. The second was white plastic mulch with 75%CWR but WUE was the first. The last was recorded at non-mulch. From eight treatments conducted on the experiment two combinations of mulching materials and water levels which are WPM * 100% ETc and WPM *75%ETc were not significantly different at ($p<0.05$) but WPM *75% ETc has the highest value on water use efficiency.

RECOMMENDATION

Therefore, from eight treatments conducted in the experiment, the combination of WPM with 75%ETc was recommended in water-stressed areas. The recommendation was also extended to different researchers for considering the effect of mulching thickness, crop type, and agro-climatic zone impact on the yield of crop and soil moisture conserving.

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