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Research Article

Effect of Deficit Irrigation and Mulch on Field and Water Productivity of Tomato Under Drip Irrigation at Ambo Agricultural Research Center, West Shewa, Ethiopia

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Abstract

Ethiopia produces far fewer tomatoes than the world average due to poor management techniques. It was found that the soil moisture and agroclimatic conditions affected how tomatoes reacted to water management during irrigation. In order to assess the impacts of irrigation level and mulch types on the yield, yield components, water productivity, and economic return of drip irrigated tomato production, a field experiment was carried out at the Ambo Agricultural Research Center Farm Site in 2021–2023. The experiment was a two-factor factorial experiment arranged in a randomized complete block design. The two factors were the four irrigation levels (55%ETc, 85%Etc, 70%ETc and 100%ETc) and three mulch types (no mulch, wheat straw mulch, and white plastic mulch). The two-year data on fruit yield, yield components, and water productivity were subjected to analysis of variance using SAS 9.4 software with a significance level ($p \leq 0.05$). least significant difference test was applied for statistically significant parameters to compare means among the treatments. The best soil moisture depletion levels, as determined by statistical analysis, are 100% ETc, 85% ETc, and 70% ETc, with marketable fruit yields of 56,405 kg/ha, 45,331 kg/ha, and 41,769 kg/ha, respectively. As for mulch types, the best practices are wheat straw mulch and white plastic mulch, with marketable fruit yields of 45,721 kg/ha and 44,514 kg/ha, respectively, for the study area. However, the results of the partial budget analysis results showed that, with net incomes for onion production in the research region of 1,350,930 ETB/ha and 1,367,071 ETB/ha, respectively, 85% ETc and wheat straw mulch are the economically optimal methods.

Keywords

Irrigation Level, Mulching, Yield, Water Use Efficiency

1. Introduction

Ethiopia's economy is dependent on agriculture, which contributes 43 percent of the GDP (Growth Domestic Product) and 90 percent of exports [1]. It also employs 83 percent of the active population [2]. Agriculture is primarily rain-fed and thus highly dependent on rainfall. But the uneven temporal and spatial distribution of rainfall has significantly affected the agriculture. The challenge of food insecurity due to its dependency on rain–fed and inability to develop the irrigation potential in Ethiopia is a concern and it is also a bottleneck problem in Ethiopia [3].

Irrigation is practiced in Ethiopia since ancient times producing subsistence food crops. However, modern irrigation

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systems were started in the 1960s with the objective of producing industrial crops in Awash Valley. Currently, the government is giving more emphasis to the sub-sector by way of enhancing the food security situation in the country. Irrigation is always required to produce high yielding crops with minimum water consumption and safe guarding the environments. With future water scarcity and climate change, management of water will become an increasingly important issue in intensive vegetable production [4]. Improving water productivity using proper irrigation method will reduce the additional water requirements in agriculture [5]. In Ethiopia, lack of research topics selected based on farmers true problems or needs, lack of capital to implement modern irrigation methods and lack of integrated soil and water management practices are among major constraints and challenges identified in the area of irrigation water and crop management practices [2].

Drip irrigation is an irrigation method that allows precisely controlled application of water and fertilizer by allowing water to drip slowly near the plant roots through a network of valves, pipes, tubing and emitters [6]. Drip irrigation, with its ability to provide small and frequent water applications directly in the vicinity of the plant root zone has created interest, because of decreased water requirement and possible increase in production [7]. Until recently, drip irrigation has been limited to large-scale commercial farming systems. Such systems require high pressure through the use of boosters or pumping systems, making it even more expensive and out of reach for small-scale farmers. However, appropriate, affordable, and accessible irrigation technologies that are within the reach of smallholder farmers can provide a basis for increased agricultural production and income generation. Innovation of low cost, small-scale technologies and water storage units has dramatically improved the lives of millions of poor farm families in developing countries [8].

Mulching is a promising strategy by which water loss can be minimized with a substantial amount [9]. For instance, plastic mulches consisting of white or black color as observed by a study [10] directly affect the microclimate around the plant by modifying the radiation budget of the surface and decreasing the soil water loss, resulting in more uniform soil moisture and a reduction in the amount of irrigation water. Similarly, straw mulching has been reported to improve the water use efficiency of crops and thereby yield increments have also been possible.

Deficit irrigation scheduling is one way of maximizing water use efficiency for higher yields per unit of irrigation water applied. The crop is exposed to a certain level of water stress either during throughout the whole growing period. The expectation is that any yield reduction resulting from the water stress will be insignificant compared with the benefits gained through diverting the saved water to irrigate other crops. For deficit irrigation and its schedules to be successful, some knowledge of crop response to water stress at specific growth stage or entire season is essential.

Integrated use of mulch and deficit irrigation is methods by which crop production, productivity of water and soil resources are enhanced. Mulching is a promising strategy by which the water loses can be minimized with a substantial amount [9]. Thus, integrating mulching with other mulch is paramount importance for sustainable crop production particularly in small-scale irrigation and water stress areas where agriculture is hampered by insufficient rainfall [11].

In Ethiopia, tomato ranks fourth in total production (5.45%) after Ethiopian cabbage, red pepper and green pepper are third in area coverage (4.49%) next to red pepper and Ethiopian cabbage from vegetable crops cultivated. Its national mean yield is 6.2 ton/ha [12, 13]. This is by far below the world average 34.84 ton/ha which is due to poor management practice in Ethiopia. The response of tomato crop to irrigation level was found to be different in different agro-climatic and soil conditions [14]. It is therefore imperative to test the performance of irrigation level in conjunction with mulch in Ambo condition that is characterized by different soil and climate. Hence, this experiment was undertaken to evaluate the feasibility of irrigation level with mulches for tomato cultivation in terms of yield, water use efficiency and economics.

Objectives

1) To evaluate the effects of applying deficit irrigation and mulch on maize yield and water productivity of drip irrigated tomato production.
2) To evaluate economic advantage of deficit irrigation and mulching in maize production under drip irrigated tomato production.

2. Materials and Methods

2.1. Description of the Study Area

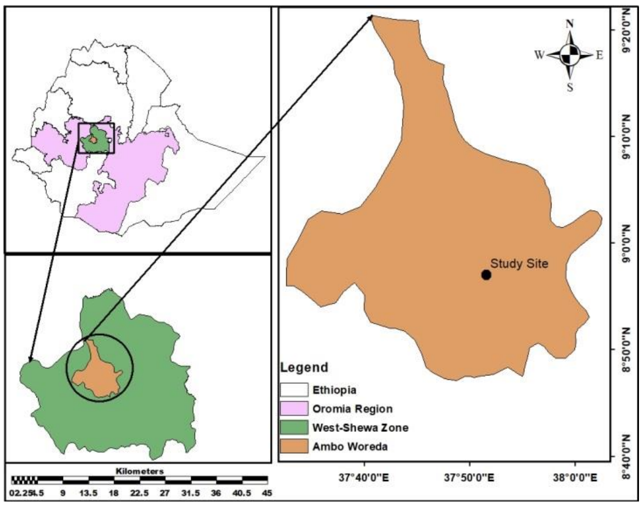

Figure 1. *Location of Study Area.*

The experiment was conducted at Ambo Agricultural Research Center Farm Site, Ambo Woreda, West Shewa Zone.

The geographical location of the site is 37^0 52' E longitude and $8^0$57' N latitude and 2180 m.a.s.l altitude. The area lies in the semi-arid belt 115km from Adis Abeba and experienced a bimodal rainfall within a mean annual precipitation of 1003.7 mm. The mean maximum and minimum temperatures of the area range from 26.4°C and 10.3°C respectively. The soil texture of the study area is clay.

2.2. Experimental Design and Field Layout

The experiment was a two-factor factorial experiment arranged in RCBD (Randomized Complete Block Design) with three replications. The two factors were deficit irrigation and mulch types. The deficit irrigation method has four levels (100%ETc, 85%ETc, 70ETc and 55%ETc), whereas mulch types have three levels (no mulch, wheat straw mulch and white plastic mulch). No mulch with 100%ETc were considered as a control for the experiment). A total of twelve treatments with three replications were allocated on 36 plots of size 4.5 m × 3 m (13.5 m^2), each with spacing of 2 m between plots and blocks. The experiment will be done under dry conditions.

Table 1. *Treatment Combination.*

Irrigation level	Mulch Types		
	No mulch	**Straw Mulch**	**White Plastic Mulch**
100% ETc	T1	T5	T9
85% ETc	T2	T6	T10
70% ETc	T3	T7	T11
55% ETc	T4	T8	T12

2.3. Drip Installation Procedure

Overhead tanks (barrel) system 1 barrel per each block was used to provide the right pressure for delivery into the pipe system. The stand for placing water container" 200 litre barrel" was constructed 1.5 m above the ground from locally available wood. The barrel top was covered in order to prevent evaporation loss and direct rainfall. The height of the stand was providing pressure to open drip emitters. A mainline with a diameter of 20 mm was connected to the inlet valve. The filter was attached to the mainline which distributes relatively clean water to the manifold and for each replication control valves was connected on the manifold. The laterals were connected to the manifold at 0.75m spacing. Control valve was also connected to the manifold to control the water flow to each plot separately. The end of the laterals and the manifold was closed with end caps. The size of main line was 20mm, size of lateral was 16mm, and dripper spacing was 30cm.

Water source is one of the important components for drip irrigation, there may be different water sources that can be used for drip irrigation but for the experiment the water source was Huluka river. Water was conveyed from river to the experimental site by lined canal and collected in to the overhead tank manually.

Irrigation frequency or irrigation interval refers to the number of days between irrigations during periods without rainfall. It was scheduled from crop consumptive use rate and on the amount of available moisture in the crop root zone.

2.4. Application of Mulch

White plastic mulch

White Plastic polyethylene treatments was used over the ground surface, especially along the maize plant rows at 15 days after planting. Thickness of plastic mulch ranging from 1.25 was used. Holes was cut into the plastic film at plant spacing to allow the plant vegetation to emerge.

Straw mulch

Wheat straw mulch was applied to the experimental plots at 6tone/ha. at 15 days after transplanting

2.5. Water Application Method and Irrigation Scheduling

The total available water of soil and allowable soil moisture depletion level of $0.14m^3/m^3$ and 40% respectively were considered from FAO 56. Water was applied to plots using Parshall flume with a throat width of 3 inches. CROPWAT 8.0 was used to determine the reference evapotranspiration (ETo: mm day-1) using the fifty years climate data (mean annual minimum and maximum temperatures (◦C), wind speed (km day -1), sunshine hours, and relative humidity (%)) collected from Ambo Agricultural Research Center agrometeorological station. The crop evapotranspiration (ETc) was calculated as a product of ETo and crop coefficient (Kc) Crop coefficients of maize in sub-humid areas were adopted from FAO 56.

$$ETc = ETo*K$$

Where: Kc in fraction
ET_c in mm/day and
ETo in mm/day

2.6. Irrigation Scheduling

For a 40% level of soil water depletion and knowing ETc and soil infiltration rate, the frequency and duration of application was determined for as follow [15].

Fraction of surface area wetted (P)

$$P = \frac{W}{(Lr*Le)}$$

where, P = fraction of surface area wetted

W = surface area wetted (m^2)
Lr = plant row spacing (m)
Le = emitter spacing (m)
Surface Area Wetted (w) was taken from MoA [15] for Different Emitter Flow and Soil Infiltration Rate.
Depth of application

$$d=\frac{(P*Sa)D*P}{(Eu*Ea)}$$

where, d = depth of application (mm)
Sa = Total available soil water (mm/m)
D = plant root depth (m)
Ea = field application efficiency (%)
Eu = emission uniformity (%)

Irrigation interval (i)

$$i=\frac{(P*Sa)D*P}{ETcrop}$$

where, i = irrigation interval (day)
ET_{crop} = Crop Water Requirements (mm/day)
Flow duration (t) was

$$t=\frac{d*Lr*Le}{qe}$$

where, t =flow duration (hr.)
q_e = emitter flow rate (lt/hr)

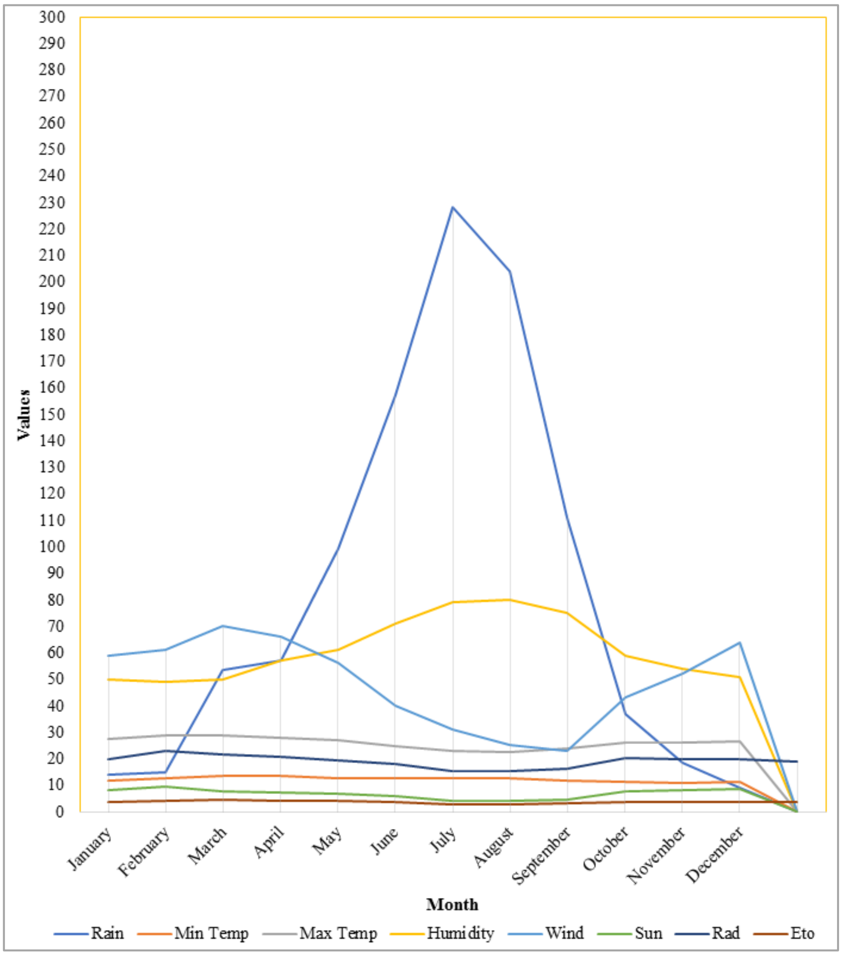

Figure 2. *Climate data of the study area.*

Table 2. *Soil water characteristics of the study area.*

Soil Type (USA Soil Texture Classification)	Soil Water Characteristics		
	FC (m^3/m^3)	PWP (m^3/m^3)	FC – PWP (m^3/m^3)
Clay	0.36	0.22	0.16

2.7. Crop Management

Tomato seed of "Melka Shola" variety was used as test crop from Melkas Agricultural Research Center. The seeds were sown in the well-prepared nursery seed bed field on 1st October. The seedlings were transplanted onto the experimental plots after 45days. The recommended fertilizers rates of 150 kg/ha for Urea and 200 kg/ha for NPS were applied during transplanting in this experiment [16]. One times hand weeding was used to control weeds. The data of yield and total amounts of water applied were used to evaluate the effects of drip lateral spacing and mulching on onion crop and water productivity.

3. Data Collection

3.1. Fruit Yield and Yield Components

The yield and yield component data were collected from 4 central rows and the marketable and unmarketable fruit yield were differentiated. the weight of its marketable and unmarketable fruit yield was taken and converted to hectare base and fruit yield per hectare (kg ha-1) was used for the analysis to determine effects of deficit irrigation level and mulching on fruit yield.

3.2. Water Productivity

Water productivity was calculated by a ratio of total marketable fruit yield (kg/ha) to the total water applied through the growing season in (m^3 /ha) according to Nangia et al. [17] using the following equation.

$$WP = \frac{Y}{ETc}$$

Where: WP is water productivity (kg/m^3)
Y is grain yield (kg/ha)
ETc is the seasonal crop water applied (m^3/ha).

3.3. Economic Analysis

The economic analysis of the experimental treatments was done using partial budget by using the costs of mulch and man power for application of mulch for the mulch treatments and manpower costs for irrigation water application in case of deficit irrigation application treatments using the following formula.

$$TR = Y * P$$

Where: Y is the adjusted fruit yield (kg)
P is the average market price (ETBirr/kg)

$$NI = TR - TC$$

Where: NI is net income
TC is total cost
TR is total return
ETB is Ethiopian Birr

$$TC = MC + LC$$

Where: TC is the total cost incurred due to treatment variation
MC is the Mulching material cost in ETBirr and
LC is the Laboure cost in ETBirr
Finally, the percent marginal rate of return (MRR) was calculated by the following formula:

$$\text{MRR} = \frac{\Delta \text{NI}}{\Delta \text{TC}} * 100\%$$

Where: MRR is marginal rate of return
ΔNI is the difference between the total income and variable costs in ETBirr and
ΔTVC is the additional unit of expense in ETBirr, between the two treatments.

4. Data Analysis

The two-year data of fruit yield, yield components and water productivity were subjected to ANOVA (Analysis of Variance) using SAS 9.4 (Statistical Analysis software) with significance level $p \leq 0.05$. LSD (Least Standard Deviation) test was applied for statistically significant parameters to compare means among the treatments.

5. Result and Discussion

5.1. Effects of Irrigation Levels on Marketable Fruit Yield, Plant Height, and Water Productivity of Tomato

The result showed that there were no significant interaction effects between deficit irrigation level and mulch types on fruit yield, yield components, and water productivity due to the deficit irrigation level.

The analysis results of the main effects showed that plant height is not affected by a deficit irrigation level. Marketable fruit yield, unmarketable fruit yield, and water productivity were significantly affected by the deficit irrigation level. The highest marketable fruit yields of 46,405 kg/ha and 41,769 kg/ha were recorded at 100%ETc and 85%ETc respectively. The highest fruit yield damage of 4,597 kg/ha was recorded from 100%ETc and the lowest damage of 2,442 kg/ha and

2,375 kg/ha were recorded from 55%ETc and 70%ETc respectively. The highest water productivity of 12.82 kg/m^3 was recorded at 55%ETc and the lowest was recorded at 100%ETc. Cutting irrigation from 4500 m^3/ha to 4185 m^3/ha increased the amount of marketable tomato fruit produced by a significant amount, as reported by a study Simonne et al. [18].

The study of IDE [19], confirmed that an 85%ETc treatment increased the output of tomato marketable fruit. The study of Fang et al. [20] found that the greatest marketable and total tomato output was 80% ETc. Sharma et al. [21] confirmed that the application of 440 mm/ha water is found to be agronomically feasible for Woramit tomato production.

Table 3. Effects of irrigation levels on fruit yield, yield components and water productivity of tomato.

ETc (%)	Plant Heigh (cm)	Marketable Fruit Yield (kg/ha)	Unmarketable Fruit Yield (kg/ha)	Water Productivity (kg/m^3)
55	50.922	38,026^{b}	2,442.14^{c}	12.82^{a}
70	51.722	41,769^{ba}	2,375.8^{c}	11.1383^{b}
85	51.956	45,331^{a}	4,015.6^{b}	9.7850^{c}
100	52.578	46,405^{a}	4,597.2^{a}	8.2261^{d}
LSD (0.05)	NS	4,853.7	196.83	1.1363
CV (%)	16.67	16.22	8.07	17.52

5.2. Effects of Mulch Types on Marketable Fruit Yield, Plant Height, and Water Productivity of Tomato

The analysis result of the main effect showed that plant height was not affected significantly by mulch types, but marketable fruit yield and water productivity were affected by mulch types significantly. The highest marketable yields of 45,721 kg/ha and 4,514 kg/ha were obtained from white plastic mulch and wheat straw mulch. The lowest marketable fruit was recorded without mulch. The highest water productivity of 11.13 kg/ha and 10.76 kg/ha were obtained from white plastic mulch and wheat straw mulch. The lowest was recorded from no mulch. the maximum total yield was obtained from plots treated with plastic mulch as observed by CSA [22]. The result is in line with the findings of Regasa et al. [23], who reported that mulching could mitigate the effects of water stress on plant growth and produce the maximum number of fruits and unit fruit weight. The report proved that the maximum number of fruits was attained when grass mulch was applied. The findings of Alemayehu et al. [24] also confirmed that crops under straw mulch produce higher branches, fruit weight, and total yield. The research result of Sharma et al. [21] confirmed that application of straw mulch is found to be agronomically feasible for tomato production in Woramit.

Table 4. Effects of mulch types on fruit yield, yield components and water productivity of tomato.

Mulch Types	Plant Heigh (cm)	Marketable Fruit Yield (kg/ha)	Unmarketable Fruit Yield (kg/ha)	Water Productivity (kg/m^3)
No Mulch	50.375	38412^{b}	3866.7^{a}	9.5963^{b}
Wheat Straw Mulch	51.992	44514^{a}	3334.9^{b}	10.7567 ^{a}
White Plastic Mulch	53.017	45721^{a}	2871.4^{c}	11.1271 ^{a}
LSD (0.05)	NS	3459.2	160.63	0.7692
CV (%)	12.56	13.75	8.14	13.45

5.3. Effects of Irrigation Level on Economic Return of Tomato

The partial budget analysis results of the application of deficit irrigation for the production of tomatoes under drip irrigation revealed that 85% ETc resulted in the highest net income of 1,350,930 ETB/ha (Table 5). According to Regasa et al. [21], based on the partial budget analysis, the highest net benefit was obtained via 440 mm of water.

Table 5. *Effects of deficit irrigation level on economic return of tomato.*

ETc (%)	Total Yield (kg/ha)	Adjusted yield (kg/ha)	Total Income (ETB/ha)	Total Variable Cost (ETB/ha)	Net Income (ETB/ha)	MRR (%)
55	38026	35223	1232805	50400	1,182,405	-
70	41769	37592	1315720	59000	1,256,720	864
85	45331	40798	1427930	77000	1,350,930	523
100	46405	41765	1461775	95200	1,366,575	86

5.4. Effects of Mulch Types on Economic Return of Tomato

The partial budget analysis results of the application of mulch for the production of tomatoes under drip irrigation revealed that the application of wheat straw mulch resulted in the highest net income of 1367071 ETB/ha (Table 6). According to Sharma et al. [21], based on the partial budget analysis, the highest net benefit was obtained with straw mulch. Straw mulch is better for economic profitability [24]. The finding of Sharma et al. [21] confirmed that application of straw mulch is found to be economically feasible for tomato production in Woramit.

Table 6. *Effects of mulch types on economic return of tomato.*

Mulch Type	Total yield (kg/ha)	Adjusted yield (kg/ha)	Total Income (ETB/ha)	Total Variable cost (ETB/ha)	Net Income (ETB/ha)	MRR (%)
No Mulch	38412	34570.8	1209978	0	1209978	
Wheat Straw Mulch	44514	40062.6	1402191	35119.61	1367071	447.3
White Plastic Mulch	45721	41148.9	1440212	343306.9	1096905	D

6. Conclusion

Poor management practices have caused Ethiopia to produce much fewer tomatoes than the global norm. It was discovered that the way tomatoes responded to water management during irrigation varied depending on the soil and agroclimatic conditions. In order to assess the viability of using mulches along with irrigation levels for tomato cultivation in terms of yield, water use efficiency, and economics, this experiment was conducted. The experiment's results showed that the maximum marketable fruit yields, at 45,331 kg/ha and 46,405 kg/ha, respectively, were obtained from 100%ETc and 85%ETc. 55%ETc produced the maximum water productivity of 12.82 kg/m^3. The highest marketable fruit yields of 45,721 kg/ha and 44,514 kg/ha resulted from white plastic and wheat straw mulch, respectively. Significantly high-water productivity of 11.13 kg/m^3 and 10.76 kg/m^3 were recorded from white plastic and wheat straw mulch, respectively. The partial budget analysis result indicated that 85% ETc and wheat straw much gave the highest net income of 1,350,930 ETB/ha and 1,367,071 ETB/ha, respectively. We therefore draw the conclusion that the optimal practices for irrigated tomato production under drip irrigation in the study area are 85%ETc and white plastic mulch.

Abbreviations

GDP: Growth Domestic Product
RCBD: Randomized Complete Block Design
Kc: Crop Coefficient
ET_c: Crop Evapotranspiration

ETo: Reference Evapotranspiration
P: Fraction of Surface Area Wetted
W: Surface Area Wetted
Lr: Plant Row Spacing
Le: Emitter Spacing
d: Depth of Application
Sa: Total Available Soil Water
D: Plant Root Depth
Ea: Field Application Efficiency
Eu: Emission Uniformity
i: Irrigation Interval
t: Flow Duration
q_e: Emitter Flow Rate
MRR: Marginal Rate of Return
NI: Net Income
TVC: Total Variable Cost
MC: Mulching Material Cost
LC: Laboure Cost for Mulch Applications
WP Water Productivity
Y: Grain Yield
NI: Net Income
TC: Total Cost
TR: Total Return
ETB: Ethiopian Birr

Conflicts of Interest

The authors declare no conflict of interest.

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